THE CURRENTS

IN

BELLE ISLE STRAIT

FROM INVESTIGATIONS OF THE TIDAL AND CURRENT SURVEY IN
THE SEASONS OF 1894 AND 1906.

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TABLE OF CONTENTS.

PART I.

General explanations of the behaviour of the current.
Tidal character of the current, as now ascertained.
Old theory of constant inward flow, found incorrect.

TIDE AND CURRENT IN THE STRAIT.

Characteristics of the tide, as shown by the tide curves.
Tidal ebb and flow in the strait.
Greater flow in one direction.

ELEMENTS WHICH MAKE UP THE CURRENT.

General character reviewed. Tidal element. Element of dominant flow. Actual current in the strait, when the elements are combined. (Tables of strength of tidal streams and maximum velocities.)

CHARACTER OF THE CURRENT RECAPITULATED IN BRIEF.

Springs and neaps. Diurnal inequality. Dominant flow. Maximum speed. Cross currents. Wind disturbance. Temperatures, &c.

PART II.

I. OBSERVATIONS OBTAINED AND ILLUSTRATIVE PLATES.

Survey of 1894. Survey of 1906. (Table of positions of stations.) Plates described. Weather conditions. (Table of mileage and direction of wind.)

II. TIME-RELATION BETWEEN CURRENT AND TIDE.

Slack water and maximum strength. Technical explanation. Current tables. Data for current tables.

PART II—*Concluded.*

III. DOMINANT FLOW.

Possible causes of the dominant flow discussed.
Review of the causes of this flow, and its relation to the Labrador current.
A meteorological cause investigated.
Greatest dominant flow observed, in relation to weather conditions.
Temperature of the water in relation to the dominant flow.
Practical indications of the direction of the dominant flow.

IV. UNDER-CURRENT.

Practical objects in view, in its examination.
Relation to the surface current. Relation to the dominant flow.
Application of the results.

V. WIND AND CURRENT.

Wind and waves. Waves produced by measured amounts of wind.
Wind and tidal streams. Change of wind at turn of current.
Disturbed conditions. Effect of wind on the current.
Wind influence on surface temperature.
Conclusions regarding wind disturbance.

VI. TEMPERATURE OF THE WATER.

Practical objects in view. Instruments and observations.
Deep temperatures, in relation to other regions.
Results explained.
Icebergs in relation to water temperature.
(Table of surface temperature and deep temperatures, in 1894 and 1906.)

TIME.—The time used throughout is Atlantic Standard, for the 60th meridian West.
BEARINGS.—All bearings and directions are magnetic; the variation being 34° West.

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FROM THE INVESTIGATIONS OF THE TIDAL AND CURRENT SURVEY IN THE SEASONS OF 1894 AND 1906.

OTTAWA, February 5, 1907.

This strait is of the first importance to Canadian commerce; as a great circle from Montreal and Quebec to the middle of Great Britain, passes directly through it. It thus forms the natural gateway for the St. Lawrence traffic, and is used as long as the season permits; as it affords a shorter route than through Cabot strait and south of Newfoundland. The traffic through Belle Isle strait is consequently almost as great as on the St. Lawrence itself.

In the season of 1894, when the currents in this strait were first investigated by this Survey, the traffic passing Father Point was on the average 98 steamships per month in each direction, with an aggregate tonnage of 156,650 tons (registered), representing an actual carrying capacity of fully fifty per cent more than this. As the increase since then has been remarkably great, the importance of correct information regarding the currents in this strait is very evident, more especially as there is a considerable amount of fog in the early part of the season.

The strait itself lies east and west (magnetic). It has a width of 10 to 18 miles for 50 miles of its length, beyond which it widens rapidly in both directions. The north shore is bold, and the water off it, is deep; the south shore is low; but dips off rapidly into about 30 fathoms. At its narrowest part, the depth of water does not exceed 35 fathoms all the way across.

Observations obtained.—The current in the strait has now been examined in two different years; in 1894 for nearly two months in different parts of the season, from July 7 to August 9, and from September 5 to 25. The intervening month was spent in investigating the currents in Cabot strait, the other entrance to the Gulf of St. Lawrence. In 1906, the whole season was given to Belle Isle strait, from June 7 to September 22.

In both years, the observations were obtained from a steamer anchored at carefully selected positions; the steamer thus serving as a fixed point from which to measure the strength and direction of the current. In 1906, a schooner was also employed, and moored at one position in the middle of the strait throughout the season. The positions chosen avoided any local irregularities or tide rips. The observations taken were continuous, day and night, both on the steamer and on the schooner.

A self-registering tide gauge has been in operation since 1894, at Forteau bay, in the narrowest part of the strait near its western end. This record has afforded a very satisfactory comparison with the behaviour of the current, as observed simultaneously in the strait during the two seasons.

The most modern methods were employed in the investigation of the currents, the velocity being measured, during each half hour, continuously day and night, by means of a current meter registering electrically on board. This measurement was made at the standard depth of 18 feet; and the direction of the current was observed by means of a float attached to the stern, which was illuminated at night. The observations also included systematic comparisons of the under-current with the surface current, and the water temperature on the surface and throughout the depth. These were supplemented by complete meteorological observations; the direction of the wind and its velocity measured by an anemometer on board, barometer readings, a barograph record and air temperatures.

The best apparatus and specially devised appliances were used to secure trustworthy results, when compared with the record of the tide in the strait, as obtained by the self-registering tide gauge.

The observations were made with the assistance of Mr. S. C. Hayden, and Mr. W. J. Carnes for the night work, aided later by Mr. J. H. Penney. Captain T. G. Taylor also gave his co-operation in addition to his regular duties, and the officers on board were always ready to help. On the schooner, the observations were entrusted to Mr. A. W. Carlton, with the co-operation of Captain A. F. Bruce and the help of the mate, Mr. D. Young.

PART I.

General explanations.—It may be stated in general terms that the current in Belle Isle strait is fundamentally of a tidal character; the typical or standard movement of the water consisting of tidal streams which are nearly equal in the two directions, during flood and ebb. It may thus be described as very similar to a detached section of the Lower St. Lawrence. But the tide here has less range, and is consequently more liable to disturbance; and it also shows at times a strongly marked inequality between the day and night tides. The difference between the two tides of the same day may thus be nearly as great as the change from springs to neaps.

All the variations in the tide are represented by similar variations in the current; and the current is further complicated by a tendency to greater flow one way than the other. This flow may be in either direction; and although the tidal fluctuation goes on without interruption, the water will make in one direction more than in the other for several days together, or possibly for a week or more. At times when the tidal streams are weak, the flow may be sufficient to prevent the current from turning at all, as it ordinarily would.

This flow in a dominant direction can be explained clearly by describing the drift of an iceberg. The berg will drift up and down with the flood and ebb, but in the course of the day it will make on the whole a considerable gain to the westward, if the flow is that way. The average amount of this gain, in knots per hour, is the measure of the flow. This is found from the current meter record, by eliminating the tidal fluctuation itself, by a method of differences.

What it is that causes this flow we will not discuss at present: though it may be well to note here that it cannot be attributed to wind influence, as the wind is frequently against it The most careful observations show that local wind in the strait itself has remarkably little influence on the current: and throughout the season of 1906, although the weather was broken, the gales which occurred did not cause any appreciable disturbance.

Under these conditions, it will make the whole matter more intelligible to give first, as Part I, a general account of the characteristics of the current as now ascertained from the observations in the two seasons of 1894 and 1906. Following this, in Part II, more detail will be given from the observations made; and this, with illustrative examples in the plates, will show the different ways in which the current may behave, when the various elements that make up the actual result are combined. It will remain to consider the best way of treating the results to reduce them to the most practical form possible for the use of mariners.

It may be well to emphasize that, with currents of this complex character, it is not possible to form trustworthy conclusions from observations taken in the day time only. Because of the marked inequality in the range of the tide, it is sometimes the day tide and sometimes the night tide which is much the larger of the two. The current in the strait shows a corresponding inequality, and consequently there may be times when the tidal streams will turn very distinctly in their usual directions at night, but in the day time they are too weak to do so, or vice versa. It is for such reasons as these that day observations alone, as taken in the course of an ordinary hydrographic survey, may lead to conclusions regarding the nature of the currents, which are so far from correct as to be actually misleading.

Also, with regard to wind disturbance, very little that is trustworthy can be arrived at, without a careful examination of the behaviour of the under-current at a depth greater than that to which the disturbance extends. When such observations are compared with surface directions, and with the measured velocity of the wind, sound conclusions can be reached; but inferences based upon surface indications alone, may be classed as unreliable. The closest attention has been given, both in taking the observations and in their reduction, to detect the influence of the wind on the current and to estimate its amount.

Tidal character of the current.—In general terms it may be said that the normal current in the strait is out and in, with the tide. The strait lies almost exactly east and west, magnetic, and the flood stream sets westward from the Ocean toward the Gulf of St. Lawrence, and the ebb stream sets eastward, or outwards toward the Ocean. The tidal flow in the two directions is nearly equal, and it amounts at the most to some two or three knots per hour each way. Although the tidal regularity may often be seriously modified by a tendency to a greater flow in one direction than the other, as already mentioned, it is still true that the tidal element is the leading feature.

This general statement is given in contrast to the old idea so long prevalent, that the current in Belle Isle strait is a constant one, flowing continuously inwards towards the Gulf. On the maps in some physical geographies, this was definitely represented. A branch from the Arctic current which runs southward along the outer coast of Labrador, is shown to run in at Belle Isle strait, and passing around the west side of Newfoundland, to find its way out again, around Cape Ray, into the Atlantic.

Old theory of constant inward flow.—This theory, as above explained, could hardly be more contrary to the facts, and it is therefore very misleading to shipping. For it was assumed by vessels entering Belle Isle strait, that the current must always be in their favour in making the run westward to round the eastern end of Anticosti. But they were not in reality in advance of their reckoning as they supposed, but turned too soon; which may account for some of the wrecks that used to be frequent in that region. One of the earliest services rendered by the Survey of Tides and Currents was to disprove this erroneous idea. In Reports published in December, 1894, and October, 1895, it was explained that the current in Belle Isle strait is tidal in its character; also, that the general set along the west coast of Newfoundland is north-eastward, not south-westward as this theory supposes; and further, that the outgoing water through Cabot strait is on the Cape Breton side, and is quite distinct in its density, temperature and other features, from Belle Isle water; while around Cape Ray the tendency of the water is to make inwards towards the Gulf, to balance the outflow on the other side of Cabot strait.

It is surprising that the erroneous theory regarding a constant inward flow through Belle Isle strait should have gained so much currency, when the tidal character of the current in the strait was ascertained as far back as 1854.

This information is contained in a report by a Newfoundland official, Mr. M. H. Warren, which was found after the publication of the results obtained by this Survey that are referred to above. The report is addressed to the Colonial Secretary of Newfoundland and is dated February, 1854. Mr. Warren states that he had been more than twenty times through the strait in sailing vessels, and thrice in a steam sloop; and as Superintendent of Fisheries for the Newfoundland Government, he had spent the months of July and August of the previous season cruising in the strait and had anchored several times in every harbour and also rowed in a boat from harbour to harbour. He was accordingly requested to report on the navigation of the strait, and in the course of his report he says:—"The tides in the Strait of Belle Isle are generally regular, flowing east and west; on the rising tide setting to the westward, on the falling tide to the eastward alternately every six hours. When the wind prevails east or west several days, it influences the tides; sometimes with a prevalence of east or west winds, on the change of the tide there is merely slack water. In the event of a calm, there is scarcely any danger of the tide hauling a vessel on-shore on the Labrador coast, the tides generally setting off the Points. On the coast of Newfoundland, from Cape Bauld to Cape Norman, the tides are not regular but set into Sacred and Pistolet bays, which are very dangerous."

The idea of a constant inward flow appears to be based on the drift of icebergs, and as they are more usually seen drifting inwards, it has been inferred that this is the constant direction of the current. The converse of this is much nearer the truth however; as it may be stated in general, that when icebergs are numerous at the outer end of Belle Isle strait and are also found within the strait, this indicates that the direction of the current has been predominantly inwards during the few days previous, while the absence of icebergs indicates a current predominantly outwards. This of course refers to floating bergs, and not to bergs which may be aground near either shore. The inward flow is thus made visible, whereas the outward flow is not so.

The small amount of indraught towards the strait, relatively to the general drift of the Labrador current, is also shown by the icebergs; for only a very small percentage of the bergs off the outer end of the strait ever enter it. Captain Vaughan, who resided four years on Belle Isle, states in a pamphlet on the subject that for ten icebergs which enter the strait, there are fifty that pass the mouth and go southward. In doing so they follow the general drift of the Labrador current which passes Belle Isle; and the larger bergs also ground at the entrance to the strait.

This general southward drift past the mouth of the strait is corroborated by Mr. P. J. Colton, lightkeeper of the south light on Belle Isle. He has lived there all his life, and has now been in charge for five years. He describes the icebergs, which follow the outer Labrador coast, as passing the mouth of the strait and keeping right on towards the outer capes of Newfoundland at Fogo. It is only the bergs that are close to the Labrador side that enter the strait, and these are not one in ten of the whole number. After they thus enter the strait, if they come out again at all, it is always along the Newfoundland side, as viewed from Belle Isle.

Publication of correct information.—Every endeavour has been made to dispel these misleading ideas which would be so dangerous to shipping if accepted. In December, 1895, a notice to Mariners was issued by the Marine Department, stating briefly the true character of the currents in Belle Isle strait. This information was re-issued by the United States Hydrographic office as Notice No. 4 of 1896. In reviewing the Annual Report of the Marine Department for 1895, the Liverpool "Journal of Commerce" makes the remark: "Probably the most valuable portion of this report is the clear statement with respect to currents in the Strait of Belle Isle. . . . . This survey work should be placed in the hands of every navigator trading in the region concerned, without charge." One of the plates in the report of this Survey was also printed as a diagram on the "North Atlantic Pilot Chart" for March, 1897, with an explanation of the correspondence between the current and the tide in the strait. The report on Belle Isle strait has been extensively reviewed in maritime periodicals, especially in Germany. Good summaries of the results were given in the "Annalen der Hydrographie," the "Fortschritte der Ozeanographie," and in the Book Notices in Petermann's "Mitteilungen," Part 9, 1896; Nos. 596*a* and *b*. Reviews were also given in the "Annales de Géographie," and the "Scottish Geographical Magazine." The information is now given in the Supplement of 1899, to the third edition of the "Newfoundland and Labrador Pilot," published by the Admiralty. It is thus hoped that the former erroneous views will no longer be accepted.

TIDE AND CURRENT IN THE STRAIT.

Characteristics of the tide.—The tide in Belle Isle strait, as recorded by the gauge at Forteau bay, has a range which is seldom as much as five feet. It is similar in type to the usual tide of the North Atlantic on these coasts; as for example the tide at Halifax. It shows with the usual distinctness the alternation from springs to neaps; but as the range is so small, the neap tides are apt to be irregular. It differs from the ordinary Atlantic tide in showing very markedly the diurnal inequality. When the moon's declination is high, north or south of the equator, the two tides in the day are very unequal; one of the two having a range of as much as 40 per cent more than the other. The declination influence is thus almost as strongly marked as the change with the moon's phases from springs to neaps; but the effect of the moon's distance, which in the Bay of Fundy is the strongest feature in the tide, is here so small as to be quite obscure.

The effect of the wind on the height of the tide is well marked, as may be expected with a strait open at both ends, and where the range is so small. The secondary undulation is always evident on the tide curve, and goes on continually just as it does at other tidal stations on the open Atlantic coast. It is here about the average, as compared with Cape Race, St. Paul island, Halifax and Yarmouth.

Tidal ebb and flow in the strait.—The foregoing characteristics of the tide in Belle Isle strait have been described with care, because every feature which the tide shows is distinctly reflected in the current. This comes out clearly when the strength of the tidal streams is measured with a current meter and the direction noted every half hour, day and night. The strength of the current changes in the same way as the tide, from springs to neaps; when the diurnal inequality is pronounced, the current alternates in exact correspondence with the variation in the range of the tide; and any irregularity in the tide curve is equally noticeable in the current.

As the observations of the current were continuous, it is clear that any variation in speed will be quite evident, although there may be a preponderance of flow in one direction rather than the other; and even if this preponderance is so great as to result in a continuous flow in one direction, the variation is still distinctly marked. It may therefore be stated that the tidal element in the current is always present, and that it occasions a fluctuation in complete accord with the tide, showing all the variations which the rise and fall of the tide exhibits. The most marked of these variations is the diurnal inequality, which in the case of the current is distinctly greater than the change from springs to neaps.

Greater flow in one direction.—If the current were due solely to the rise and fall of the tide, it would always be of equal strength in both directions; for even with diurnal inequality, the tidal streams would be equal in pairs. But in fact, it is the exception for the speed of the current to be quite equal in the two directions. There is thus on the whole, a gain in favour of one direction; or an over-balance of flow inwards or outwards as the case may be. This is equivalent to a continuous flow in one direction, super-imposed upon the ebb and flow of the tide. It is thus best to regard it as a separate element which, in combination with others, makes up the movement of the water as actually met with.

This view is the more reasonable, as a dominant flow of this character may go on for a week at a time, or even longer, in one direction or the other; and it must therefore be considered as something distinct from the more regular tidal fluctuations. In amount, the average rate at which the water gains or makes in the one direction may be considerably over one knot per hour. This movement comes to an end by gradually decreasing in amount and thus allowing the tidal streams to resume their equality of speed in the two directions. In this behaviour, the under-current acts almost always in the same way as the surface current; so that the whole body of the water appears to be affected alike.

It is this element of dominant flow which brings the icebergs into the strait, or keeps the strait clear of floating bergs, as the case may be: according as its prevailing direction is inwards or outwards. In the season of 1906, icebergs came into the strait as late as the middle of September, at a time when the dominant flow was inwards.

In describing this element in the current, we have been careful to keep to a statement of the facts. The reason for it, or the causes which give rise to it, we will discuss later on; as it is a question whether or not it is periodical, and what relation it has to astronomical factors or to weather conditions.

THE ELEMENTS WHICH MAKE UP THE CURRENT.

With the general explanations above given, we may now describe more definitely the various elements which make up the current as actually found. This is the best way to approach the subject: for an attempt to describe and classify the various ways in which these currents behave, would give the problem all the complexity which it presents to anyone who endeavours for the first time to grasp it, or make it intelligible to others. We will therefore take up in order the different elements, which contribute to the total strength of the current, and explain their relative importance as components in producing the actual result. Their strength, as deduced from the observations obtained, will show the share which each of them contributes, and thus enable the effect of their combined action to be understood.

General character.—To begin with a brief review of the explanations already given, it may be said in general that the current in Belle Isle strait is primarily tidal in its character. While under the control of the tide alone, it will turn regularly and run with equal strength in each direction; the flood setting westward and the ebb eastward. But in addition to this tidal fluctuation, the water has almost always a tendency to make through the strait in one direction more than in the other. While the tidal fluctuation goes on uninterruptedly, the water is thus making a continuous gain to the westward, or to the eastward, as the case may be. This over-balance in one direction we may term the element of dominant flow, which is super-imposed upon the usual tidal elements. It gives rise to much complication, as it is large in relation to the strength of the tidal streams, especially at the neaps when they are weak.

(I). *Tidal element.*—While the current is under the control of the tide alone, without any dominant flow in either direction to complicate matters, the usual astronomical conditions are to be distinguished. The effects which are chiefly noticeable in the tide and current in this strait are (1) the ordinary change from springs to neaps, with the moon's phases; and (2) the diurnal inequality which is greatest when the moon is at its maximum declination, north or south of the equator. This inequality is quite as distinct in the current as in the tide itself. At the maximum, its amount is so large that the difference in the strength of the current during the course of the day is distinctly greater than the difference between springs and neaps. On the other hand, the variation in the moon's distance from perigee to apogee, has no appreciable influence in this region; although in the Bay of Fundy it is a factor of the first importance.

(*a*.) Current without diurnal inequality. At times when the moon is on the equator or near to it, the tidal streams are equal in the day and night. The neap streams have on the average 45 per cent of their strength at the springs; which is practically the same percentage as the variation in the range of the tide from springs to neaps. The average velocities as found from the measurements throughout the season, are as follows:—

Current at Spring tides; flood or ebb velocity	1.50	knots.
" Neap tides " "	0.68	"

It is to be noted that only one or other of these can be without diurnal inequality in the same lunar month: for if the moon is on the equator at the full and change, there will be the maximum of diurnal inequality at the quarters, or vice versa.

(*b*.) Current with diurnal inequality. At times when the moon is at its maximum declination north or south of the equator, the day and night streams are most unequal. In the 24 hours, one flood and one ebb are very strong, while the other two are weak. These weak streams have on the average only 31 per cent of the velocity of the strong ones. They correspond with the dates at which there is greatest inequality in the range of the tide itself. The average velocities of the two unequal currents are as follows:—

At Spring tides; strong flood and strong ebb	2.27	knots.
" weak " weak ebb	0.72	"
At Neap tides; strong flood and strong ebb	1.04	"
" weak " weak ebb	0.32	"

It is to be noted that the two strong currents may both occur in the day time and the weak ones at night, or vice versa, according as the moon is in north or south declination.

(*c*.) Cause of the tidal streams. It is evident that these are the counterpart of the rise and fall of the tide itself; and it is interesting to compare their strength with the range of the tide. The average range at springs is 3½ feet, and at neaps 2 feet. The extreme range, when there is diurnal inequality, is about 5 feet. The ebb and flow through the strait is no doubt due, as in other straits elsewhere, to a difference in the time of high and low water at its two ends.

(II). *Element of dominant flow.*—This is the gain which the water makes in one direction more than the other, notwithstanding the tidal fluctuation which checks it or help it on. It is the over-balance of flow inwards or outwards through the strait. It will be best first to give the facts regarding this element in the current; as there is so strong a tendency to explain it off-hand, as being necessarily due to wind disturbance. With full knowledge of what occurs, an explanation can better be sought.

This element of dominant flow has been carefully determined throughout the season, for each day on which observations were secured. Its amount is found from the difference of tidal velocity in the two directions during any complete period of 24 hours of observation. It is usually impossible to obtain a correct result unless all the four tidal streams of the day are included, because of the large diurnal inequality. But however large the inequality may be, the flood and ebb streams should be equal in pairs; and if both pairs show a difference in favour of one direction, this indicates a dominant flow that way; and the amount can be determined.

To ascertain with accuracy the greatest dominant flow in each direction which occurred during the season, its amount was worked out exactly from the velocity in each half hour during the course of the days on which the greatest flow occurred, the length of the lunar day being taken, with the following results:—

Eastward, 1.30 knots, on July 31. The current running continuously eastward without turning, but fluctuating from 2.76 knots to 0.50 knot with the ebb and flood.

Westward, 1.69 knots, on Septemder 10. The current running continuously westward without turning, but fluctuating from 2.65 knots to 0.64 knot with the flood and ebb.

The average in each direction from all complete days on which observations were secured during the season, from June to September, is as follows:—

Dominant flow while Eastward, average................	0.68 knot.
" Westward, average.................	0.65 "

The last figures cannot be taken to indicate the relative amount of inward and outward flow that takes place on the whole. But they do indicate the average speed at which the water may make through the strait in one direction or the other, when this average is taken for a period of considerable length.

Actual current in the strait.—It is thus evident that the dominant flow is often sufficient to overcome the ordinary tidal streams, and prevent the current from turning as it otherwise would. This will occur when the tidal streams themselves are weak, as they may be at the neaps, or when the diurnal inequality is large. As an actual result, the current may turn only once during the course of the day; or there may even be a continuous flow in one direction with a fluctuation in speed corresponding to the tide.

The different elements which make up the actual current as found, may be classed in three groups as follows:—

Period: the Synodic month.	I. Moon New or Full. Springs. Strong currents.
	II. Moon at the Quarters. Neaps. Weak currents.

Period: the Tropical month.	I. Moon at Max: declination North. Greatest diurnal inequality.
	II. Moon on Equator. No inequality due to tidal elements.
	III. Moon at Max: declination South. Greatest diurnal inequality in the reversed direction to North declination.
(Causes or period under discussion.)	I. Dominant flow Eastward; either very strong or weak.
	II. No dominant flow; tidal elements alone operating.
	III. Dominant flow Westward; either very strong or weak.

When it is considered that some combination of these various elements must always occur, and that all possible combinations will take place in course of time, the great complexity of the current, as actually found in the strait, is fully explained.

It will be unnecessary to give all possible combinations in a tabular form, with numerical values based upon the various elements deduced from the observations. The extreme velocities which can result from any combinations are given in the following table; and for comparison, the greatest velocities as observed in the two seasons. These extremes must occur when the dominant flow at its greatest strength runs with the strongest tidal stream which the diurnal inequality can produce, or when it runs against the weakest possible tidal stream, which it overcomes and reverses.

TIDAL ELEMENTS IN THE CURRENT.

True velocities of the Tidal Streams themselves, when unaffected by any Dominant Flow in either direction.

Conditions Necessary.	Tides Equal. Day and night tides the same. (Moon on Equator.)		Diurnal Inequality. (Moon at maximum declination North or South of Equator.)	
At times when there is no dominant flow in either direction:—	Flood westward.	Ebb eastward.	Flood or Ebb.	Ebb or Flood.
	Knots.	Knots.	Knots.	Knots.
At Spring Tides...	1.50	1.50	2.27	0.72
At Neap Tides..	0.68	0.68	1.04	0.32

LIMITING VELOCITIES OF THE CURRENT.

Table showing the combination of conditions necessary to produce the greatest velocities possible in the flood and ebb directions: and the greatest possible reversal of the ordinary directions, by the dominant flow.

Conditions Necessary.		Diurnal Inequality at its Maximum.			
		Stronger Streams.		Weaker Streams.	
		Flood setting Westward.	Ebb setting Eastward.	Flood. (Reversed in direction.)	Ebb. (Reversed in direction.)
		Knots.	Knots.	Knots.	Knots.
If dominant flow is WESTWARD, at greatest ever observed; namely, 1.72 knots per hour.	At Springs.......	3.99	...	....	—1.00
	At Neaps.......	2.76	...	....	—1.40
If dominant flow is EASTWARD, at greatest ever observed; namely, 1.40 knots per hour.	At Springs......	.	3.67	—0.68	...
	At Neaps........	..	2.44	—1.08	

EXTREME VELOCITIES OBSERVED.

As measured in the two seasons of 1894 and 1906, under such combinations of conditions as were then met with.

Year.	Flood setting Westward.	Ebb setting Eastward.	Flood. (Reversed in direction.)	Ebb. (Reversed in direction.)
	Knots.	Knots.	Knots.	Knots.
Extremes as observed in 1894............... ...	3.39	2.49	—0.22	—1.33
Extremes as observed in 1906.......	3.45	2.83	—1.02	—1.43

FURTHER POINTS EXPLAINED IN PART II.

There is little difference discernible between the current on the two sides of the strait. Cross currents may be met with at its two ends where it widens out, especially at the eastern end where the Labrador current passes its mouth. At slack water, the current in turning usually veers completely around; but this does not amount to a cross current, as it is so weak.

The possible causes of the dominant flow and its relation to wind disturbance are discussed under those headings, in Part II. Some practical indications are there given to enable the mariner to infer its probable direction.

The disturbance of the current, caused by the direct action of the wind, is remarkably little considering the situation of this strait. The amount of such disturbance as found from the relation of the surface current to the under-current and from other indications, is explained in Part II.

The temperature of the water does not afford a reliable indication of the direction of the tidal streams or of the dominant flow at the time; nor can reliance be placed on the water temperature to indicate the proximity of icebergs.

The preparation of current tables to show the time of slack water or maximum velocity, and the methods of utilizing the results of the observations for that purpose, are also discussed in the second part of this report.

PART II.

I. OBSERVATIONS OBTAINED; AND ILLUSTRATIVE PLATES.

Surveys of 1894.—In this season, the current in Belle Isle strait was examined in both July and September, at the narrowest part of the strait near Amour Point. To avoid the tide rips which occur off this point, a section line was chosen a little to the eastward, on a line from Green island, at the south side, to the red cliffs on the north shore, which lie immediately east of Loup bay. The width of the strait is there 11½ miles; and three stations were chosen on this section: Station A at one mile off Green island; Station B in the centre; and Station C three miles from Red cliff. The positions of these stations are shown on the chart, Plate I. The usual depth is 30 to 40 fathoms; but the water is here much deeper near the north shore. The bottom appears to be bare rock running in ridges parallel with the direction of the strait. The surveying steamer was anchored at these stations for one or two days at a time; and was moved from one to another to ascertain any difference in the current at the two sides of the strait, while the same conditions of wind and weather prevailed.

The tides were observed simultaneously at Forteau bay within 12 miles of these stations. In July, the times of high and low water were noted; but in September after the tide gauge was erected there, a continuous record day and night was obtained for both tide and current; although the latter was much interrupted by bad weather. It was thought better in September, to keep to the two channels on the north and south sides of the Centre Bank: and accordingly only two stations were occupied; one being Station C, and the other intermediate between A and B, near Station U.

In this season, one of the lighthouse supply steamers was placed at the disposal of this Survey for a period limited strictly to three months. The general itinerary was as follows:—

June 29. Left St. John, N.B., calling at Halifax for materials for the tide gauge, and at Sydney for coal.

July 7 to August 9. Surveys in Belle Isle strait and vicinity; and erection of tide gauge at Forteau bay.

August 10 to 31. Returned to Cabot strait to make surveys there; and called at Sydney for coal and supplies.

September 1 to 25. Second trip to Belle Isle; and further surveys in the strait.

September 26 to 29. Returned from Belle Isle strait to Pictou; including a call at St. Paul island and some later temperature observations in Cabot strait.

The dates during which the currents followed the tides with the greatest regularity and the conditions of weather then prevailing, are given below. The directions of the wind are magnetic, the same as all other bearings. The magnetic variation is 34° W.

Monday, July 9, to Friday, July 13. Wind moderate, from the west or variable in direction. During the four days there were 60 hours westerly wind, averaging 9 miles an hour.

Thursday, July 26, to Saturday, July 28. During two previous days, July 24 to 26, there were 36 hours of westerly winds averaging 15 miles an hour; and 12 hours of easterly and variable winds averaging 14 miles an hour. From July 26 to 29, winds from N.W. to S.W. for 54 hours, averaging 15 miles an hour.

Monday, September 17, to Friday, September 21. Including the two days previous, or in all from September 15 to 21 there were 72 hours of westerly winds, averaging 15 miles an hour; and 72 hours of easterly winds, averaging 8 miles an hour.

The following summary shows the velocity of the current in the two directions which in these periods was nearly equal.

July 9 to 11 at Station A, and July 12 and 13 at Station B.
During flood tides, maximum westward: 1.16 to 1.98 knots per hour.
During ebb tides, maximum eastward: 1.30 knots per hour.

July 26 to 28 at Station B.
During flood tides, maximum westward: 1.80 to 1.98 knots per hour.
During ebb tides, maximum eastward: 1.08 to 1.26 knots per hour.

September 17 to 21 at Station C.
During flood tides, maximum westward: 1.02 to 2.04 knots per hour.
During ebb tides, maximum eastward: 0.92 to 1.81 knots per hour.

The inequalities of the current in the last instance correspond with the diurnal inequality in the tides themselves.

In Plate II a comparison of the current with the tide is given, from the Report of December 1894. This publication of the behaviour of the current in the form of a diagram, showed distinctly for the first time the tidal character of the current in Belle Isle strait. This was so different from the opinions then accepted, that the diagram was published by The United States Hydrographic office, in the North Atlantic Pilot chart for March, 1897, accompanied by an explanation of the nature of the current, summarized from the above Report.

Surveys of 1906.– A summary of information regarding the stations at which anchorages were made, from June 7 to September 22, is given in the table below; as well as those of 1894, which were occupied in July and September, as stated above. The letters for the stations were continued from those of 1894, to avoid confusion. The positions of the stations are also shown on the chart, Plate I. The hours of observation are the total for each station, though most of them were occupied several times at different dates. In 1894, much of the work was done without anchoring, which reduces the number of hours on this basis, as shown in the table. The total time in which observations were taken in 1906, while actually at anchor, amounted during the season to 1,113 hours; equivalent to 46 days of 24 hours, or 93 days of 12 hours.

Year.	Stations.	Depth in Fathoms.	Hours of observation of Current	Positions in Belle Isle Strait.
1894.	A	42	55 hours.	0 6 mile N. 30 W. from east end of Green island.
	B	38	76 "	6 8 miles S. 39 E. from west point of Loup bay.
	C	32	158 "	3.4 miles S. 58 E. from west point of Loup bay.
	G	41	52 "	2 8 miles N. 15 W. from east end of Green island.
	H	37	8 "	10 7 miles S. 42 W. from Greenly island lighthouse.
	J	36	5	6 3 miles N. 40 W. from South light, Belle Isle.
1895	K	42	73 "	6.0 miles N. 41 E. from Cape Bauld lighthouse.
	L	43	46 "	8 6 miles N. 43° W. from South light, Belle Isle.
	M	30	(Sch'r. buoy)	7 0 miles S. 60 E. from Amour Point lighthouse.
	N	28	40 hours.	7.7 miles S. 64° E. from Amour Point lighthouse.
	P	39	219 "	6 6 miles S. 5° W. from Wiseman head.
"	Q	38	259 "	3 5 miles S. 8 W. from Carrol Point.
"	R	33	196 "	3 0 miles N. 9° E. from mouth of western of the two Halfway brooks.
"	S	47	51 "	7 5 miles S. 1° E. from Geenly island lighthouse.
"	T	30	105 "	7 4 miles S. 13° W. from Carrol Point.
"	U	43	63 "	2 5 miles N. 33 E. from east end of Green island.
"	V	46	61 "	4 8 miles S. 70 E. from west point of Loup bay.

Plate I. An outline chart of Belle Isle strait on which the positions of the stations are shown where anchorages were made in the strait in both seasons, 1894 and [illegible]. The position of the tide gauge in Forteau bay is also indicated, as well as the point at which the schooner was moored for current observations in 1906.

Plate II. Illustrative of periods of tidal equality in 1894 and 1906, when the tidal streams were of equal strength in the two directions. The correspondence between tide and current shows clearly the tidal character of the current in the strait.

In 1894, the current observations and tide curves are shown, day and night, from Wednesday to Friday, September 19 to 21. The marked diurnal inequality in the current will be noted, which corresponds with the inequality in the tide itself. This inequality is pronounced because the moon was near its maximum declination North, which it reached on the 22nd at 10 h. These tides are just before the neaps; the moon being at its Last Quarter on the 22nd at 8 h.

In 1906, the tide and current are shown day and night from Monday to Friday, August 20 to 24. The current is in evident accord with the tide. These observations begin at the springs, the moon being New on the 19th at 21 h. The diurnal inequality is decreasing; the moon being 12° North at noon on the 20th, and crossing the Equator on the 23rd at 4 h.

The position of Mean Sea Level on the tide diagram is at 3.15 feet on the scale given. This is the level found from three complete years of tidal observation at Forteau bay, in 1898 to 1900. But it is to be noted that it varies quite appreciably from one year to another.

Plate III. Further illustrations of the various features in the behaviour of the current, compared with the simultaneous tide curve. The first period shows continuous observations from Monday to Saturday, June 18 to 23. It includes the spring tides shortly after Apogee; the moon being in Apogee on the 18th, and New on the 21st at 19 h. The diurnal inequality is pronounced, as the moon is in high North declination throughout the period, being 14° North on the 18th at 18 h., maximum North on the 22nd at 16 h., and 20° North on the 23rd at 17 h.

The second period is continuous from Monday to Saturday, July 9 to 14. The tides fall off towards the neaps which are included at the end of the period. The diurnal inequality decreases, as the moon crosses the Equator on the 12th; and on the first days, the predominance of flow to the eastward is very evident. The amount of this dominant flow is so great as to allow the tide to turn only once a day, with the assistance of the diurnal inequality; although the tidal fluctuation itself is as pronounced as usual.

This affords a good example of the misleading conclusions which might easily result from observations taken in the day time only; as the current does not turn during the day time, and the turn which does occur is at midnight.

Plate IV. Illustrative of periods of pronounced dominant flow in the current. In the first period shown, from July 30 to August 2, the amount of tidal fluctuation is quite as much as usual; yet the dominant flow eastward is so strong that the current seldom actually turns. Two other short periods are given, from July 16 to 18 and September 10 and 11, when the predominance of flow in one direction or the other is so great as to exceed the tidal fluctuation and produce a continuous current.

During the week from Monday to Saturday, September 17 to 22, the dominant flow is westward on the whole. In the first three days it is not sufficiently strong to prevent the current from turning on the ebb; but it increases in amount, and towards the end of the week the current only turns once a day.

At the end of this plate, the direction and amount of the dominant flow is shown, as observed throughout the season. A comparison is given with the barometric gradient, or the difference in the height of the barometer, between Belle Isle and St. Johns, Newfoundland. From all the meteorological investigations made, in relation to the dominant flow, this was the only weather condition found to be at all comparable with it. This will be explained more fully later on.

The manner in which the dominant flow is separated from the tidal element in the current, may be illustrated from the first current period in this plate. If a horizontal line were ruled in, to equalize the tidal fluctuations, the distance of this line from the actual line of "no current" would represent the amount of the dominant flow to the eastward. This explains graphically the method by which the amount of the dominant flow is obtained for each complete day of observation throughout the season, as given in the separate diagram at the end of this plate.

Weather conditions. The mileage and direction of the wind during the periods shown on the plates, are given in the table following. These periods for the wind commence one day previous to the beginning of the observations of the current and tide.

Periods.	N.N.W. to N.N.E.	N.E.	E.N.E. to E.S.E.	S.E. to S.W.	W.S.W. to W.N.W.	N.W.	Average mileage per day.
Plate II.—*Periods of Tidal Equality.*							
1894. From September 18 to 21, noon to noon. Three days	81	94	35	329	248		262
1906. From August 19 to 24, noon to noon. Five days.		18	438	185	249		178
Plate III.—*Current and Tide compared*							
1906. From June 17 to 23, noon to noon. Six days.		676	891	700	358		438
" From July 8 to 14, noon to noon. Six days.				162	2074		373
Plate IV.—*Examples of Dominant Flow.*							
1906. From July 29 to August 2, noon to noon. Four days. Dominant flow Eastward.			37	301	932		317
" From July 15 to 18, noon to noon. Three days. Dominant flow Eastward.			302	305	1079		562
" From September 9 to 11, noon to noon. Two days. Dominant flow Westward.		223	152	120	66		280
" From September 16 to 22, noon to noon. Six days. Dominant flow Westward.	228	113	28	48	993	485	316

The barometric conditions corresponding to the periods of dominant flow shown on Plate IV, were as follows:—Period, July 29 to August 2; barometer falling rapidly from 30.15 at noon on the 28th to 29.70 at noon on the 29th; then rising gradually on the whole to 30.05 by noon of August 2. Period, July 15 to 18; barometer falling steadily from 30.35 at noon on the 12th to 29.55 at noon on the 18th. Period, September 9 to 11; barometer rising steadily from 29.35 at noon on the 7th and reaching a maximum of 29.90 at 8 o'clock on the 11th. Period, September 16 to 22; barometer falling from 30.25 at noon on the 16th to a minimum of 29.45 at 16 o'clock on the 20th, and rising again to 29.80 by noon of the 22nd.

II.—TIME RELATION BETWEEN CURRENT AND TIDE.

In most estuaries and straits, it is found that the tidal streams ebb and flow in correspondence with the rise and fall of the tide. It is therefore best for practical purposes to determine the time of slack water in relation to the time of high and low water; as there is usually a constant difference in time between the two; and when once this time-interval is determined, the time of slack water can be found from a tide table. This is the method given for the St. Lawrence, and for the strong tidal streams of British Columbia, in the tide tables published by this Survey.

But in Belle Isle strait there is much difficulty in devising a method which will give a satisfactory relation between the tide and the current, owing to the complexities which it presents. While there is a dominant flow in one direction, it is evident that the tidal stream in that direction will not only be stronger but will run for longer than the usual period. It may thus often happen that the time at which slack water occurs is early or late by an hour or more, in relation to the time of high and low water. The difference of time is no longer constant or anywhere near it. For when the dominant flow happens to be in the other direction, the slack water which before was too early will become too late, and vice versa. Not only so, but when the tidal streams, or one of them, becomes so weak as to be overcome by this element of dominant flow, there may no longer be an actual slack water at all, at which the current stops and reverses its direction.

There is another point in the movement of all tidal streams however, which bears a constant relation to the time of the tide. It is the point of time at which the strength of the current is greatest, as this necessarily stands directly related to the moment of half tide; for the tide itself is then rising or falling at its maximum rate. It is also evident that this relation is not altered if the whole body of the water is moving in one dominant direction, while the ebb and flow due to tidal influence is taking place. This then affords a time-relation between current and tide which is not affected by the element of dominant flow, however great its strength may be relatively to the tidal streams themselves.

To take an extreme example, if the dominant flow is in the ebb direction, and the flood is too weak to turn at all, the maximum of the flood is represented by the minimum current in the ebb direction; but the time at which this occurs is necessarily the same as it would be if the tidal streams were unaffected by any other element in the current.

Technical explanation. To those acquainted with analytical geometry, this varying behaviour of the current can be stated so simply, that the result of the changes is self-evident. For either tide or current, the time can best be measured along the horizontal axis, and the height or speed vertically.

The tide is ordinarily represented by a sinusoid; but when there is diurnal inequality this becomes modified. The tide then becomes a pair of similar sinusoids of different amplitudes placed alternately along the horizontal axis; the total period of the two sinusoids making up the length of the lunar day. The generating circles of these sinusoids have diameters which represent the amplitudes of the two tides of the day. During the course of the tropical month, the two circles expand and contract in diameter, so as to be equal when the moon is on the equator and to attain their maximum difference alternately when the moon is at maximum declination north or south respectively.

The current curve representing the tidal streams in the two directions is the derived function of the tide curve, its nodal points on the horizontal axis corresponding with high water and low water on the tide curve, and its maxima with the half-tide points. The points of intersection with the axis are the times of slack water, and the maxima in the two directions occur at half flood and half ebb. At times of diurnal inequality in the tide curve, this is equally well marked in the current curve.

The element of dominant flow is simply a raising or lowering of the horizontal axis above or below the axis of symmetry in the curve itself. It is thus obvious that when dominant flow supervenes, it makes no real change in the tidal fluctuation itself, which is still the same function of time and amplitude. It merely adds a constant to the ordinates on the one side of the axis, and deducts from those on the other.

The effect of this change in the position of the axis is obvious; as it occasions a serious displacement in the time-position of the points where the curve intersects the axis, which represent the slack waters. When this change in position is sufficient, the axis becomes tangential to the curve at one of its maximum points; and two of the slack waters are merged in one which is out of time by half the period of flood or ebb. It is thus clear what the altered behaviour of the current will be, when a greater or less amount of differential flow is super-imposed on the tidal element, with or without diurnal inequality.

The matter of chief importance is that the maxima on the current curve are not displaced in time by any amount of change in the position of the horizontal axis; even when this is sufficient to make a maximum pass over to the other side of the axis, and become a minimum with opposite sign. On the other hand, as the amount of this change increases, the points of intersection, which represent slack water, approach each other in pairs, coalesce, and eventually disappear. The maxima on this curve are thus the only points which maintain a fixed time-relation to the original tide curve. From an analytical stand-point this is self-evident and merely requires to be stated.

The advantage of continuous measurement of current velocity with a current meter registering to the hundredth of a knot is also obvious; as the true times of maximum and minimum speed can thus be ascertained accurately by plotting the record.

Current tables.—The method thus indicated is the only one by which current tables can be prepared that will not become incorrect when there is a dominant flow in one direction or the other. In the preparation of these tables, the time of maximum flood and ebb can be deduced from the times of half tide, by differences which are always constant. The time of maximum flood, as given in the current table, must be taken to mean either the greatest strength of the inward current in the flood direction, or the least strength in the ebb direction, according as there is or is not a dominant outward flow against it, with sufficient strength to overcome and reverse it. A corresponding meaning must be given to the maximum ebb.

Such tables would not always indicate the actual direction of the current; but they would show when a vessel would meet with the greatest or least amount of help or hindrance in the direction in which it is going, that can occur at the date in question. This would be of more practical value than an attempt to give the time of slack water, which would only be correct while there was no appreciable amount of dominant flow; as there may then be no slack water for twelve hours or more. On the whole, a table of slack water would only be approximately correct for about half the time, and the other half of the time it would be misleading.

These tables of maximum flood and ebb would afford complete information as to the actual current, if the added element of dominant flow could by any means be predicted, or ascertained at the time, by the mariner. This question we discuss in the next section, on Dominant Flow; and at the close we note the only indications of a practical kind, which enable the probable direction of this flow to be known.

Data for current tables. It may be well to give the data regarding both the time relations between current and tide which are referred to above, that result from a complete reduction of the observations.

(1) Time of Slack Water. Based upon observations at times when a difference of flow in a dominant direction is least.

Time of Slack Water in Belle Isle strait, after the time o[illegible]gh Water or Low Water at Forteau bay:—

	h. m.
In 1894. General average from 28 comparative observations in July and September.	1:44
In 1906. Mean value, from 14 daily averages as explained below. June to September . .	1:39
Slack Water after H. W. or L. W. Final result.	1.41

Note on method. In order to eliminate completely the effect of the dominant flow in making the time of slack water too early or too late, the daily averages are taken for all four tides of the day. The true difference of time between slack water and the tide is thus best determined. Although one general average for both high-water and low-water slack is thus found, the value is more trustworthy than if the result were derived from the tides taken separately

(2) Time of Maximum Strength. Based upon all good and definite observations obtained throughout the season of 1906, at the stations in the central part of the strait.

Time of Maximum Strength of the current (or minimum when the current is reversed) after the moment of Half Tide, rising or falling, at Forteau bay:—

				h. m.
At Station P	Average of	36	observations	1:35
At Stations Q and R . . .	"	65	"	1:26
At Station T.	"	18	"	1:16
At Stations U and V. . . .	"	17	"	1:16
Maximum Strength after Half Tide.	General Average.			1:26

Note.—The time taken as half tide at Forteau bay is the point on the tide curve at half height between high and low water, for the tide in question. There is no appreciable difference in the time-interval with the rising or falling tide, or between stations on the two sides of the strait; but as shown above, the time-interval increases as the point of observation is farther from Forteau bay, to the eastward.

In all the data here given, the observations are reduced to Standard time, and the resulting differences are thus in absolute time.

III.—DOMINANT FLOW.

This movement, as already explained, is the difference of flow in favour of one direction, when considered apart from the tidal fluctuation. Its nature will be understood from the examples given on Plate IV, which are illustrative. There is also shown on this plate the direction and amount of the dominant flow throughout the season.

The value in knots per hour which expresses the amount of this flow on each day, has been deduced from the maximum and minimum velocities in the periods of flood and ebb, as measured by a current meter at the standard depth of 18 feet.

Throughout both seasons there was almost always some dominant flow, and usually it was well marked. Allowing for interruptions in the observations, it appears that it may continue in one direction for a period of two or three days to two weeks or more at a time. When classed in periods, the result, for the two seasons of 1894 and 1906, is as follows:—

1894.—July 9 to 28.—Observations incomplete, being in the day time only. They give indications of dominant flow both westward and eastward, for periods of three to six days at a time in one direction; the amount not probably exceeding half a knot, in addition to the tidal velocity.

September 5 to 8. Observations interrupted; but showing very strong dominant flow westward, probably amounting to two knots on the average. The current ran continuously westward and fluctuated with the tide without turning.

September 11 to 21. Dominant flow westward continuously; on the 12th amounting to 0.67 knot, and afterwards not exceeding 0.18 knot, and falling to tidal equality by the 21st.

1906.—June 18 to 29. Continuous observations during two weeks. Dominant flow westward, continuously. Average during one week, 0.64 knot; during the other, 0.21 knot, falling to tidal equality. Greatest amount in any one complete day, 0.66 knot.

July 4 to 13. Dominant flow eastward. Greatest amount, 1.17 knots. On July 14, changed to dominant westward flow.

July 17 and 18. During two days dominant flow eastward, averaging 1.02 knots.

July 25 to 28. Observations off the eastern end of the strait, show that the dominant flow was eastward.

July 30 to August 4. Throughout this week, dominant flow eastward. Greatest amount 1.40 knots; current only turning once a day on some days, with the stronger flood.

August 6 to 8. Tidal equality in the two directions.

August 20 to 24. Throughout this week, dominant flow westward with little variation in amount, averaging 0.57 knots.

August 27 to 29. Tidal equality without dominant flow either way.

August 30 to September 15. Observations much broken, but dominant flow always westward when observed. Greatest amount on September 10-11, 1.72 knots, the current then running continuously westward without turning.

September 17 to 22. Dominant flow westward, increasing during the week from 1.04 to 1.59 knots.

These values show very closely the speed at which the water may make through the strait in one direction or the other, independently of tidal fluctuation. The differences between the maximum velocities of the flood and ebb, at all the four tides of the day, are taken in such a way as to eliminate the diurnal inequality also. Yet this method is not quite so accurate as if the speed at each half hour is taken as explained on page 13.

Possible causes of the dominant flow. In endeavoring to find an adequate cause, some attention must be given to the relation of the dominant flow to the under current and to wind disturbance, but as far as possible these will be left for separate consideration. There is no evident relation between the direction of the local wind and the dominant flow, which is at once obvious; while true wind disturbance occurs very seldom and is of short duration. The only explanations that seem possible, we may classify as follows:—

(1) If the cause is astronomical, the flow should run alternately in each direction for some well-defined period. The only period which the observations make at all probable is about a fortnight; which would not indicate any relation with the moon's phases, but rather with the moon's change in distance or in declination. But after careful study of the facts, no such relation can be ascertained.

(2) On examination of the tidal curves, there appears to be a change in the half-tide level, by which mean sea level in the strait is raised or lowered for several days at a time. If this change were periodic, it should correspond with one of the longer period tides, possibly in the course of the tropical or declination month. But in the harmonic analysis of three complete years of tidal record at Forteau bay, no such tide of long period could be distinguished.

(3) In looking for a meteorological cause, it must not be too hastily assumed that the wind is the only factor in question, as the result may be quite as much due to the difference in barometric pressure over wide areas. For, the direct effect of the wind would produce primarily a surface drift, whereas it is to be expected that a difference in pressure would cause a more even flow throughout the whole depth; and this corresponds better with the dominant flow which affects the whole body of the water. Examples of a true wind drift have been met with in the strait, and will be described; but they are rare in the summer season, as the winds are not heavy enough or sufficiently long continued to cause the surface drift to extend to any great depth. It is also to be noted that the dominant flow may continue for a week or more at a time in the one direction, which a wind drift would not do.

If the cause is meteorological it is therefore more likely to be found in a difference of barometric pressure over wide areas; and accordingly this question was carefully investigated with the result that a probable relation with the direction of the dominant flow has been found, which will be explained below, as it appears to afford a valuable clue.

(4) There appears to be some relation between the direction of the dominant flow and the season of the year. Its direction in the winter and early spring is made evident by the behaviour of the flat or pan ice. When the dominant flow is westward, this ice, while drifting up and down with the tidal streams, will work gradually inward; and on the other hand dominant eastward flow will soon clear the strait.

Any change in the dominant flow which takes place with the season of the year, may possibly be related to a variation in weather conditions with the different seasons; but it cannot be attributed to the direct effect of local winds. For example, in the early spring the pan ice will come in from an easterly direction while there is only a light air of easterly wind, quite insufficient to occasion any actual wind drift.

In the summer season, the direction of the dominant flow is more difficult for residents or fishermen to observe or to estimate correctly, as it is necessary to make allowance for the ordinary tidal streams; but from such information as they were able to furnish, it appears that in May and June the more usual direction is westward. In July and August it is more usually eastward, and in September and October, westward. This general estimate of its direction corresponds with the observations obtained in both seasons.

Review of the causes of the dominant flow, and its relation to the Labrador current.—There is no evidence that any true period of an astronomical character can be assigned to the dominant flow; nor can it be explained as a wind drift, due to the direct effect of local winds. The cause is apparently related to weather conditions of a general character, but their influence on the dominant flow must be indirect. Difference of barometric pressure may occasion a change of volume in the Gulf of St. Lawrence, through Cabot strait, which may have an effect on the flow in Belle Isle strait; or more probably the effect may result from a change or fluctuation in the Labrador current, which follows the eastern coasts of both Labrador and Newfoundland; such a fluctuation being presumably due to meteorological causes.

It is further possible that the direction of the flow may be influenced to some extent by the daily average level of the tide, above or below mean sea level; but this variation appears also to be due to meteorological influences, as no astronomical period can be found to correspond with it. It is stated by residents of Red bay, at the middle of the strait, that the highest tides occur with winds from the northerly quarter, between northeast and northwest; and that wind in the west or west-southwest will carry the tide lower than any other.

It is interesting to note that an actual fluctuation in the Labrador current, due to storm disturbance, is observed. This is stated by Mr. J. H. Penney, who has had a long experience on the Labrador coast. On the coast immediately north of Belle Isle, between Roundhill islands and Battle harbour, the current maintains its average speed southward while the prevailing winds continue, their direction being westerly and southwesterly. Before a northeast gale begins, the current may be reversed and set northward. It thus sets towards the direction of the coming wind, which the currents so often do in these regions. After the gale is over, it sets southward with unusual strength for four or five days.

Such a fluctuation in the general southward drift of the outside current, by checking it or helping it on, may give rise to pressure or relief laterally on Belle Isle strait; and this may have some correspondence with the predominance of inward or outward flow in the strait itself.

Meteorological cause investigated.—It appears from the foregoing explanations that the direction of the dominant flow in Belle Isle strait is probably related to weather conditions.

But to investigate the question, the basis of information is unfortunately very incomplete. There are no barometric observations available along the Labrador coast, north of Belle Isle, but only in the regions south and west of the strait. Nor are there observations of the Labrador current sufficiently continuous to reveal the character of any general fluctuation in that current due to meteorological influences, or to show whether this corresponds with an inflow which leaves that current to enter the strait, and with the outflow from it. It would also be valuable to have simultaneous tidal records to give the daily average level of the tide at the two ends of the strait, for comparison with the direction of the dominant flow.

A full explanation is not therefore to be expected, nor is it possible to state what the actual cause is, or how it operates to effect the result. Yet it may be quite possible to establish a relation between the weather conditions and the direction of the dominant flow, which is so usual that it may be regarded as of constant occurrence, and thus afford an indication of practical value.

Although the available information on the weather is limited to the region south and west of the strait, there is at least the hopeful feature that the storm centres usually pass to the southward, their tracks seldom lying further north than the line of the strait itself.

As a preliminary indication, it was found in 1894, that during the time of greatest dominant flow eastward the barometer was high and steady, whereas when the greatest westward flow occurred, a storm centre was passing over Newfoundland to the southward of the strait.

To investigate the matter as carefully as the information obtainable admits of, a special set of meteorological charts was kindly prepared by Mr. R. F. Stupart, Director of the Meteorological Service, on which the barometric lines, or isobars, were extended to cover the area of the strait. There are also four meteorological stations in the region, from which the direction of the barometric gradients can be well ascertained. These stations are on Belle Isle, at St. Johns Newfoundland, Sydney, and Southwest point of Anticosti.

Three gradients or lines of difference of barometric pressure were examined: (1) From the Gulf of St. Lawrence to the Atlantic south of Newfoundland, tending to cause a flow through Cabot strait, and thus to fill or empty the Gulf area. (2) From Southwest point, Anticosti, to Belle Isle, giving rise to a barometric gradient along the line of the strait itself, in one direction or the other. (3) A barometric gradient north or south, along the east coast of Newfoundland and Labrador, which might influence the general southward drift of the Labrador current

The results deduced from complete days, during the course of the season, showed that there were thirty-six days on which the dominant flow was greater than one eight of a knot, apart from the tidal fluctuation; on 20 days being to the westward, and on 16 days eastward On six other days the flow was small or inappreciable.

From the first comparison it appeared that the barometric gradient was usually inwards through Cabot strait, from the Atlantic towards the Gulf of St. Lawrence. It was thus always inwards when the flow was eastward, and also inwards as often as not when the flow was westward.

If the second comparison were to give any definite result, the local wind in the strait might furnish the mariner with an indication of the direction in which the gradient lies. It was found, however, that this cannot be relied upon as an indication, especially when the barometer is high and fairly steady. And the result of the comparison was to show that quite as often as not the barometric gradient through the strait was against the direction of the dominant flow.

The third comparison gave a less uncertain result. It showed that while the dominant flow was westward, the barometric gradient usually lay southward from Belle Isle to St. Johns Newfoundland; but when the gradient lay northward, the westward flow was checked or reversed. When the gradient maintained a northward direction for a longer period, the flow was mostly eastward. If the barometric observations were extended farther north, up the coast of Labrador, this conclusion might be considered more certain.

The indication resulting, which appears to be fairly definite, is that when the barometric gradient lies northward, say magnetic north, across the Gulf of St. Lawrence and along the east coast of Newfoundland, this should correspond with a dominant flow to the eastward through Belle Isle strait; whereas a gradient lying southward should correspond with a dominant flow westward.

This indication is confirmed by the weather conditions at the time that the greatest dominant flow occurred in each of the two seasons as detailed below. When the greatest eastward flow occurred, the barometer was high and steady, with a gradient lying northward from a high pressure area to the south. The greatest westward flow occurred after gales from the north and northeast, caused by a low-pressure storm centre passing across Newfoundland, south of the strait; occasioning a pronounced gradient southward. The magnetic directions, north and south, are practically at right angles to the general direction of the storm tracks.

As these areas of high and low pressure move eastward across the Gulf and over Newfoundland successively, or a little south of that line, it is not clear whether the effect is produced by the change of pressure over the Gulf, or by the gradient along the east coast of Newfoundland which may influence the general flow of the Labrador current. But in either case, if it is these north and south gradients which have the controlling influence over the flow in the strait, this would explain the want of relation between the direction of the dominant flow and the barometric gradient along the strait itself, or the direction of the local wind

Greatest dominant flow observed in the two seasons, in relation to weather conditions. — In the season of 1894, the most marked example of dominant flow to the eastward occurred on July 16 to 19. During these three days the current set westward for only 5 hours and eastward for 19 hours each day. The maximum velocity of the westward current was 1·38 knots per hour, and of the eastward current 2·44 knots per hour. The long run eastward was stronger at the beginning and the end of the time, with an interval of weaker flow between the two. The times of high water corresponded with this minimum eastward and with the maximum westward. As the moon's declination was at its maximum south at the time, the diurnal inequality would account for the difference between the actual westward current on the one flood, and the minimum of the eastward current on the other.

At the time of this dominant flow to the eastward the wind ranged from N.W. to S.W. For three days previously, from July 13 to 16, the average for 72 hours was 16 miles an hour; and from July 16 to 18, the average for 60 hours was 14 miles an hour from the same direction. This was succeeded by easterly winds and broken weather. Also, from the morning of the 14th, the difference of barometric pressure gave a barometric gradient which was inwards at Cabot strait and outwards at Belle Isle strait. This continued until the the evening of the 17th when the pressure equalized itself; and by the morning of the 19th a low pressure area developed over the Gulf which gave inward gradients at both straits, and thus reversed the conditions for Belle Isle. The effects of both wind and barometer are thus in general accord with the direction of the eastward flow. It is evident that a difference of barometric pressure should tend to produce flow from the higher towards the lower pressure, just as in the case of the wind.

The best example in 1894 of a dominant westward flow through the strait, occurred from September 5 to 8. All the indications concurred in showing that the current ran continuously in the one direction during these days; although the observations were much interrupted by bad weather. There were also about a dozen icebergs seen in the strait during this time; and their motion agreed with the regular observations in showing that the current ran continuously westward. The current then varied from a minimum of 0.54 knots per hour to a maximum of 3.15 knots, in the one direction. The tidal influence was at its least amount, at the neaps near the moon's apogee; and five successive tides had an average range of only 1½ feet.

During this continuous westward flow, the conditions of wind and barometer were disturbed and complicated, as a storm centre was passing over the northern part of Newfoundland at the time. The low pressure area of this storm centre was over the Gulf during the 5th and was nearest to the strait on the morning of the 6th, on its way eastward to the Atlantic. From the morning of the 5th till the evening of the 8th, there were 60 hours of N.N.W. wind averaging 25 miles an hour, and rising at times to 45 miles. During the remainder of the time the winds were light and variable. The westward flow thus took place at a time of severe disturbance due to the proximity of a storm centre.

In the season of 1906, the most marked period of dominant flow to the eastward occurred at the end of July, as shown on Plate IV. From July 30 to August 2, during 70 hours. the current ran almost continually eastward, either turning only once in the 24 hours or not turning at all, but only slackening during the flood period. The greatest velocity eastward was 2.76 knots, during ebb tide.

These days began with fog and rain and the barometer at 29.70. The weather gradually cleared, and the barometer rose slowly and steadily to 30.15 by noon on August 3, when easterly weather set in. The wind during these days was variable at first, but settled into the west and north-west, rising on the 3rd to 35 miles an hour.

The strongest dominant flow in the westward direction was observed on September 10 and 11, after a heavy northerly gale on the 7th and 8th. During 34 hours the current ran steadily westward without turning, though showing a well marked tidal fluctuation. The greatest velocity westward was 2.65 knots, during flood tide.

On the 5th and 7th two low pressure areas passed over the region of the strait. On the 7th the barometer was lowest in the forenoon, being then 29.35. The gale was heaviest in the early morning of the 8th, when it attained a maximum of 53 miles an hour. The barometer rose steadily to 29.90 at noon on the 11th; when it began to fall rapidly, and by 21 o'clock, heavy westerly wind set in. The westward flow was thus again associated with storm centres, which passed almost along the line of the strait itself.

Temperature of the water in relation to the dominant flow.—It is plausible to suppose that the temperature of the water in Belle Isle strait would change in accordance with the direction of the flow; for the water outside of the strait, in the Labrador current, is colder than the Gulf water; except in the spring when the water is almost at the freezing point everywhere in these regions.

It is clear from the observations that the temperature of the water falls slightly when the dominant flow is westward and rises when it is eastward. The temperature may thus be above or below its average value for the season of the year. But this cannot be taken as a definite indication unfortunately, because the disturbance of temperature due to storms is very much greater in amount.

In the heaviest gale of the season, from the north-east on August 17, the surface water was driven off or mixed with the colder under-water. The surface temperature in the strait fell consequently from an average of 53° to 44°. When so large a change may occur from an accidental cause, the relatively slight change due to the dominant direction of the flow, cannot be counted upon as an indication.

The variation in the water temperature during the season is shown in the table given further on; and the disturbing effect of the gale referred to, is there very obvious.

Practical indications of the direction of the dominant flow.—The best indication that can be given for the guidance of the mariner, is the presence or absence of floating icebergs in the strait. It may be taken for granted that there are always some icebergs in the offing of the strait, or eastward in the Atlantic. If a westward flow is dominant at the time, the icebergs while drifted up and down by the tidal streams, will make their way into the strait; whereas if an eastward flow is dominant, the strait will be free from bergs which are afloat. It is to be noted that this indication is quite independent of what may cause the flow.

To take advantage of this indication, the mariner must be able to distinguish with a fair degree of certainty, the icebergs which are afloat. If they are close to either shore, they are sure to be aground, and they may have been there for a week or more. A berg towards the north side of the strait is more likely to be afloat as the water there is deeper. In the middle part of the strait, any berg will ground if large enough. It is there a question of size, and the probability of its being aground is stronger if it is at a position where the water shallows to the westward, or if it is over the Centre Bank. The smaller bergs, well clear of the shore, are of course the most likely to be afloat.

The best indications of practical value, including the influence of weather conditions as already explained, may be summarized as follows:

(1.) If the strait is clear of floating icebergs; and if the barometer is well up and rising, or high and steady; the probability is that the dominant flow is EASTWARD. It may amount at the most to 1½ knots. The usual ebb velocity is increased by the amount of this flow, and the flood is decreased or may be reversed by it.

(2.) If there are icebergs in the strait which are afloat; and if a low pressure area is passing to the southward, indicated by broken weather; the probability is that the dominant flow is WESTWARD. It is almost certainly so after a gale from the north or north-east. It may amount at the most to 1¾ knots. The usual flood velocity is increased by the amount of this flow, and the ebb is decreased or reversed by it.

(3.) The direction of the local wind in the strait, and the temperature of the water, cannot be counted upon as reliable indications of the direction of the dominant flow.

(4.) It appears probable that on the whole there is more westward flow in the early part of the season, in May and June; that it is less pronounced in the summer when there is usually more to the eastward; and that from September onward there is more westward flow. This would correspond with the indications above given, as the weather is apt to be more stormy as the season advances.

IV. UNDER-CURRENT.

There are several objects in view in obtaining information as to the behaviour of the under-current. The primary object is to detect wind disturbance; as the wind necessarily influences the surface of the water first, and tends to cause a drift in its own direction, while the under-current continues to turn with the tide as usual. For this purpose therefore, it was best to take observations about the time of slack water, to find whether the under-current turned before or after the surface current; and whether one of the two ran for a longer time than the other, during the flood or ebb period.

A further object was to ascertain from the surface and under-current taken together, whether on the whole there was any greater flow through the strait in one direction than in the other. This was the principal object in view in the early observations of 1894, before the tidal character of the current in the strait was understood; as the problem at first was thought to be the measurement of the discharge through the strait in one direction.

The observations were made at a standard depth of 25 fathoms, which was about two-thirds of the depth of the strait. In a few instances, in the shallower parts, it was advisable to reduce this to 20 fathoms. They were taken with the deep fan employed in former seasons. It consisted of two sheets of galvanized iron passing through each other at right angles, thus making four wings, each 26 inches by 9 inches. This was weighted to 27 pounds, and suspended by patent sounding wire, by which it could be lowered to any desired depth as shown on the dial of a sounding machine. The supporting wire was so fine as to be little influenced by the surface current; and its inclination from the vertical, as measured by a clinometer, has evidently a relation to the strength of the under-current, which it is possible to ascertain. The method of calculation we do not give, as it would be technical. This simple appliance gave remarkably satisfactory results.

As it was chiefly important, for the objects in view, to determine the time of slack water in the under-current, a series of observations were taken every few minutes for an hour or two, before and after the time at which the current should turn. These observations were necessarily limited to the day time. In quiet weather they were readily obtained, and steady rain or fog did not interfere with their accuracy; but they became more difficult in rough weather, when much patience was often required; and at times when the vessel was not only rolling but also shearing at its anchor, these observations were not usually attempted. There were days also when the current did not turn, and no slack water occurred; but on the other hand, the time of the maximum velocity of the under-current was occasionally determined, which had its value for comparison.

Relation to the surface current.—As a rule, the ordinary tidal streams of the strait veer completely round in turning from east to west. At high water the veer is through north and at low water through south. This is their usual behaviour as shown by the best observations at stations near both sides as well as in the middle of the strait. Accordingly, the north or south direction was taken as the moment of slack water on the surface; as this is the cross direction, at right angles to the general line of the strait, which lies east and west magnetic. This was usually simultaneous with the minimum velocity on the current meter; but if the time was not the same, the mean of the two was taken.

The under-current, at a depth of 25 fathoms, does not veer nearly so much, but turns more sharply from the one direction to the other. With care, the time of turn could be ascertained within five minutes. If there was a short period without current, the middle of the time was taken as the moment of slack water.

It may be said that as a rule the under-current turned at the same time as the surface current. From all the reliable observations on 47 days throughout the season and at various stations, it was found to turn within four minutes earlier or later, as a general average. There is seldom more than fifteen or twenty minutes between the two, unless the time is influenced by the dominant flow, which we will refer to again. Also, the time of maximum in the under-current, which would not be affected by dominant flow, corresponds with the maximum at the surface within five minutes on the average, as found from twelve comparisons at different dates during the season.

Relation to the dominant flow.—This relation is somewhat difficult to obtain; but it is of importance to know whether the current in the direction of the dominant flow, is stronger at the surface than below. One indication of this can be found by ascertaining whether it is the surface or under-current which runs for the longer time, during the flood and ebb respectively. The observations afford a fairly definite estimate of this. A general average of the comparisons obtained during the season at stations in the middle and towards the sides of the strait, gives the following result: When the dominant flow is westward in the flood direction, the duration of the flood at the surface is longer than in the under-current, and the ebb shorter, by 12 to 15 minutes; and when the dominant flow is eastward in the ebb direction, the duration of the ebb at the surface is longer than in the under-current, and the flood shorter, by 10 to 16 minutes. These intervals represent only about 4 per cent of the usual periods of 6¼ hours of flood and ebb.

This result corresponds in general with the usual behaviour of any flowing water; as the velocity is ordinarily greater on the surface than below, by a small percentage. It therefore confirms the view already explained, that the dominant flow is not caused by wind influence, which would have a much greater effect than this on the surface current, relatively to the under-current.

Application of the results.—These general results, condensed from a very large amount of work, are important for the purpose in view; as they establish the general rule. They thus help to make plain any exceptional influence, such as wind disturbance, which may cause a departure from the usual average.

V. WIND AND CURRENT.

The best indication of the effect of wind upon the movement of the water is afforded by a difference between the surface current and the under-current, in direction or in the time at which they turn; as it can be stated definitely from the experience gained in this Survey, that the water at a depth of 20 or 25 fathoms is unaffected by any storm, at least in the summer season. A departure from the general relations already established between the surface and under-current, will thus reveal any disturbance occasioned by wind.

A change in the temperature of the surface water may also be directly attributable to the effect of the wind; which may drive off the warmer surface layer, and allow the cold under-water to come up and replace it. A similar change of density may also furnish an indication of wind disturbance in regions where the density on the surface is distinctly different from the deeper water; but this is not the case here.

During both seasons, a careful watch was kept, to detect any influence of the wind upon the movement of the water; and the continuous meteorological observations, taken on board, afforded complete weather data for comparison. But it may be stated in general that the effect of the local winds in producing a drift in their own direction is remarkably slight, considering the situation of this strait. In the line of the strait to the westward (magnetic) there is a clear stretch of 470 miles of water across the Gulf of St. Lawrence to the New Brunswick shore; and the other way it opens into the Atlantic with no other shelter than what the small island of Belle Isle affords.

Wind and waves.—The immediate effect of wind in the strait is more notably to produce waves, rather than to influence the set of the current. A strong wind blowing for only a few hours will raise quite a sea; and the waves are usually short and choppy, owing to the comparatively shallow water. The following are the best examples, where measurements were obtained; the wind being recorded by an anemometer on board, in the same position at which the waves were observed:—

In 1894, September 14; morning calm and smooth; barometer 30.34 and nearly steady. During forenoon, wind sprang up from the southwest and increased by 14 o'clock to 35 miles an hour. At 16 o'clock, waves were 6 to 7 feet high and 90 feet crest to crest. The total amount of wind which produced these waves was 182 miles, or an average of 30 miles an hour during 6 hours. Depth of water 40 fathoms. At Station U.

In 1906, July 6; morning quiet, with scarcely more than a heavy ripple from a light west wind. Barometer rose during the previous night to 30.10 and continued steady. West wind increased during the day to 35 miles an hour at 16 o'clock, and 37 miles at 18 o'clock. At 16 o'clock, waves were 6 feet high and 50 feet crest to crest. These were produced by a total of 237 miles of west wind, or an average of 30 miles an hour during 8 hours. By 18 o'clock, the waves were 8 feet high and 70 feet crest to crest, irregular, and still forming; produced by a total of 309 miles of wind, or an average of 31 miles an hour during 10 hours. Depth of water 32 fathoms. At Station R.

On July 26; morning fine, clear and nearly calm. Barometer steady at 30.10. At noon, wind began to freshen from the west. By 17:30 the waves had risen to a height of 4 and 5 feet, with a length of 40 to 45 feet, crest to crest. These were produced by a total of 132 miles of west wind, or an average of 22 miles an hour during six hours. In the evening, the wind fell and sea moderated. Depth of water 42 fathoms. At Station K.

Wind and tidal streams.—It was frequently observed, especially in unsettled weather, that if there is a change, it will occur at slack water. For example, when the barometer is low, and a change is to be expected, east wind will come up with the flood. Also a westerly wind will seem to be held back by the flood and will be light and variable till slack water, when it will come out strongly with the ebb. These changes with the tide, in unsettled weather, are exactly similar to those which are so familiar on the Lower St. Lawrence. It would thus appear to be quite as necessary to point out that the turn of the tide may influence the wind, as that the wind may cause the tidal streams to run longer in its own direction.

The large mileage of wind required to produce a true wind drift is further shown by the behaviour of the tidal streams with relation to the wind. While anchored in mid-strait, it was often found during a strong steady wind, either east or west, that the current in its ordinary change from flood to ebb would set directly into the wind for the usual tidal period. A strong wind has thus little appreciable effect, during a tidal period of five to seven hours, in checking the current on the surface. It appears to require a large mileage of wind to produce any noticeable effect by its direct action on the water.

Disturbed conditions.—The best example of a true wind drift in 1894, was observed where the strait widens westward towards the Gulf, at three stations on a line from Rich point to the Esquimaux islands. These stations were occupied from July 31 to August 3 immediately after prolonged westerly winds, and the current was found to set eastward at the centre and on both sides. The velocity amounted to 0.79 knot per hour at the centre, and 1.19 to 1.37 knots at the sides.

Although the greater part of this velocity may no doubt be due to the ordinary tidal streams, yet as the width here is 32 miles, the currents are necessarily much weaker than in the strait proper, which is so much narrower. These relatively high velocities appear therefore to be due to the wind conditions during the week preceding. From July 24 to 31, there were in all 124 hours of westerly wind, averaging 20 miles an hour, and only 48 hours of easterly wind, averaging 19 miles an hour; or in all 2,530 miles of westerly wind, and 890 miles of easterly wind. The westerly winds also continued during August 1 and 2. The layer of water setting eastward had a thickness of only 5 to 10 fathoms; which tends also to show that its movement was due to the previous direction of the wind.

In 1894 the proportionate velocities of the surface and under-current were obtained by a current meter which was lowered to a depth of 25 to 30 fathoms, for comparison with measurements made before and afterwards with the same meter at the standard depth of 18 feet, at which the speed of the surface current has always been taken.

During 19 days, from July 10 to 28, 1894, the tidal streams were almost always regular and little affected by dominant flow. Wind mileage in the 19 days: 4,942 miles of westerly winds, between N.W. and S.W., and 1,300 miles of easterly winds, between N.E. and S.E. The surface current when setting eastward with the prevailing winds, was on the average 32 per cent stronger than the under-current, and when setting westward was only 3 per cent stronger.

In September, the speed of the under-current was almost entirely deduced from the drift of icebergs. During four days, September 5 to 8, the dominant flow was westward. All the wind was westerly, the total mileage in the four days being 1,937, or 20 miles an hour on the average. The surface current, setting westward against the wind, had only 85 per cent of the strength of the under-current.

Again, during nine days, September 11 to 19, the tidal streams were regular, without a predominant flow either way. Wind mileage in the 9 days: 2,780 miles of westerly wind, and 314 miles easterly. The few observations obtained showed that the surface current when setting eastward with the wind, was much stronger than the under-current; and when setting westward, it was only just equal to it.

It is to be noted that these winds did not reverse the currents, or cause them to set chiefly in their own direction.

In the season of 1906 there were a few gales, but it is chiefly noteworthy to remark the small amount of disturbance in the current which they occasioned. We will therefore give the facts as concisely as possible.

From June 30 to July 3 the wind as observed at Port Saunders, was continuously W. and S.W., rising to 40 miles an hour on the 2nd, and amounting to a total of 2,155 miles in 81 hours, up to 21 o'clock on the 3rd. At Belle Isle, the wind was steadily W., and averaged 413 miles per day. On anchoring in the strait at Station R on July 4, the surface current in the ebb direction ran for 20 minutes longer than the under-current at 25 fathoms; and on the following morning, in the flood direction for 15 minutes longer. These amounts are quite within the usual limits; and cannot be taken to indicate any disturbance of the surface relatively to the under-current.

On August 17 a northeast gale occurred. From 8 o'clock on the 16th to 7 o'clock on the 18th, the wind held steadily in the N.E., amounting to a total of 1,550 miles in this period of 47 hours. The steamer was in Red bay on the 17th, where the full force of the wind was not obtained. At Belle Isle, the wind ranged from N.E. to N. Current observations were obtained immediately afterwards, from the morning of the 18th, at Station P. At the first high-water slack the current in veering from west to east did not pass the north point till 1 h. 05 m. after the turn of the under-current; and at low-water slack it passed the south point 20 m. before the turn of the under-current. This modification of the veer and the consequent shortening of the ebb period relatively to the under-current, were the only indications of disturbance which the current showed

In September the observations were more interrupted; but anchorages were made as promptly as possible after heavy winds. From the evening of the 3rd to noon on the 5th there were 724 miles of wind from directions between E. and N.E.; yet at Station U at mid day on the 5th, the high water slack was simultaneous on the surface and in the under-current at 25 fathoms. The turn was prompt and definitely marked in both

On the night of September 11-12 there was heavy west wind, rising to 43 miles an hour During 24 hours up to 18 o'clock on the 12th, there were 546 miles of wind between W. and S.S.W. The night of September 12-13 was calm. At Station Q, the low-water slack at mid-day on the 13th turned simultaneously on the surface and in the under-current, showing no appreciable disturbance.

The heaviest gale of the season occurred on the night of September 14-15, when the velocity in Red bay reached 68 miles an hour. For three days the wind conditions were as follows: On the 14th from 20 to 24 o'clock, W. 107 miles; on the 15th throughout the 24 hours, N. 692 miles; during the 16th and up to 6 o'clock on the 17th, N., N. W. and W., 224 miles. Total mileage during 58 hours, between north and west, 1,023 miles.

For a week before and after this time, the dominant flow was so largely westward that the current seldom turned. Accordingly, on the 17th the current, as observed in the day time at Station P, set continuously southwestward; and throughout the ebb period the surface direction was between southwest and south, while the under-current set eastward for 3½ hours. The corresponding ebb on the following day set weakly eastward on the surface as well as below. Hence the direct influence of this gale was not sufficient to overcome the dominant flow and set the surface current eastward during the ebb, even though assisted by the under-current. The gale itself is rather to be taken as an indication of a marked difference of barometric pressure, which had a general influence on the direction of the dominant flow at the time.

Wind influence on surface temperature. -In the early part of the season when the surface temperature is only 35° there is little difference between this and the under-water; but after June the surface layer rises to 45° or even 55°, while the deeper water remains almost as cold as before. This will be seen by referring to the details of the water temperatures on the surface and below, which are given in the tables appended.

A sudden change in the surface temperature may thus afford a valuable indication of wind disturbance; as the wind, especially when off shore, may drive off the surface water and allow the colder under-water to come up to replace it. A fair estimate can even be made, by careful comparison, of the depth to which the wind disturbance extends. The best examples of this during the season were as follows:-

From Red bay to Station P at the middle of the strait, the average temperature of the surface water on August 16 was 52° 7. After the gale of the 17th, the temperature on the following morning between the same points was 45°.2, and on the 20th, between Red bay and Station T, the average was still only 44°.3. This marked change was occasioned by 1,550 miles of N. E. wind, as detailed above.

From August 18 to September 1 the temperature of the surface water recovered very little, having only risen to 46° 3 by the 1st. This may have been due in part to the preponderance of westward flow, bringing in the colder Atlantic water. Consequently, the temperature of the water in the strait was not appreciably altered by the northeast gale of September 4th. The average temperature across the width of the strait, from Red bay to Station U near the south shore, as obtained on August 27, and again on September 5 after the gale, was 45°.5 on both dates.

On September 7 and 8 another northerly gale occurred. From the 7th at 12 o'clock to the 8th at 11 o'clock, there were 717 miles of wind from N. and N. by E., rising to 3 miles an hour as measured in Red bay. The average for the 23 hours was 31 miles an hour. As soon as the wind moderated, on the afternoon of the 8th, it was found that the surface temperature was 2° lower than before for two miles from the north shore, and ½ lower at a depth of 5 fathoms. At 10 fathoms there was no change. The average surface temperature for 9 miles out, to the middle of the strait, was 45°.0.

There did not appear to be any appreciable change made by the heavy west wind of September 11-12, so far as the observations obtained could indicate. But with the next northerly gale, the difference was distinct. On the 13th the surface temperature from Red bay to Station Q was 44°.0, and while at the station the same average was found. After the northerly gale of the 14th and 15th, the average from Red bay to Station P was 41° 6, showing a fall of 2½°. This must have been largely due to the gale, although the surface temperature continued to fall till the 19th and did not recover up to 22nd, which must be attributed to the dominant flow westward as indicated by all the observations since September 5th.

A remarkable example of fall of temperature due to wind disturbance, occurred off the east coast of Newfoundland between St. Johns and Cape Race, in 1903. The surface temperature towards the end of August was 50°, when, during three days, there were 1,312 miles of off-shore wind, ranging from N. W. to W. S. W. The surface temperature within three miles of the shore fell to 36° and 34°; and in a belt ten miles in width along the windward shore, it was below 45°. (See "Currents on the Southeastern coasts of Newfoundland" by this Survey; January, 1904, page 23).

Conclusions on wind disturbance.—The effect of the wind in Belle Isle strait in raising a sea quickly, is very noteworthy; but any direct effect upon the movement of the water, as far as careful observation can detect, is remarkably slight. A more noticeable effect of the direct action of the wind upon the water, is a change in the surface temperature. This may occur after a long period of quiet weather when the water has become warm for a few fathoms at the surface, resulting in a rapid fall of temperature with the depth. A heavy wind, especially when off shore, may then drive the surface water out to the offing, and allow the cold under-water to come up to the surface.

Most of the effects usually ascribed to the wind have been found on investigation to be due to other causes. Yet it is true that the wind itself may afford an indication of the existence and operation of these causes, as we have pointed out in the endeavour to account for the direction of the dominant flow. But the strong preponderance of flow in one direction during quiet weather, and the small difference in time between the surface and the under-current, show clearly that this dominant flow is not of the nature of a wind drift.

It is also noteworthy, when discussing the matter with fishermen, that only the most superficial observers give the explanation thoughtlessly that the currents run with the wind. The more intelligent of them recognize that the direct influence of the wind, in disturbing the usual tidal streams, is not great.

The actual influence of the wind upon the movement of the water, as found from the observations in July and September, 1894, and throughout the season of 1906, we may summarize as follows:—

(1) It is anything but true that the current always sets with the wind which is blowing locally in the strait; since the ordinary tidal streams as they turn, will set directly against the wind, even when it is fairly heavy. On the other hand, in unsettled weather, the wind often comes up with the turn of the tide; or it is held back until slack water by the tidal streams setting against it.

(2) There was no evidence, after any of the gales, that the wind was able to reverse the direction of the tidal streams, or that it was able to check to any noticeable extent, the dominant flow which prevailed at the time.

(3) From direct comparisons of the velocities of the surface and under-current, made in 1894, it appears that when a period of several days is considered as a whole, the current which sets against the wind prevailing at the time, is somewhat retarded on the surface. This is inferred from the velocity it otherwise would have had, as indicated by the under-current.

(4) The only other effects of the wind upon the movement of the water which can be detected, are these:—There may be a slight change in the time of veering at the turn of the current when it is weak; and the period of flood or ebb which is in the direction of the wind may become slightly longer on the surface than in the under-current.

These results are based upon observations taken as soon as the weather moderated. If the effects are greater while a gale lasts, the current must recover its usual behaviour almost at once, when the wind falls.

VI. TEMPERATURE OF THE WATER.

The chief aims of a practical character in observing the temperature of the water, were to ascertain whether there was any distinct change with the flood and ebb streams, or any pronounced difference with the direction of the dominant flow. The amount of rise or fall in temperature that takes place with a change in the direction of the current will be seen by examining the tables which follow. But the change of temperature is not sufficient to afford a definite indication of practical value as to the direction which the current has at the time. This has been explained in connection with the dominant flow. The relation of the temperature of the water to wind disturbance, has also been explained under that heading. A third object was to ascertain whether the water temperature might be relied upon as a warning of the proximity of icebergs; and on this we give some notes below.

Instruments and observations.—The temperature of the surface water was taken every four hours, with the regular meteorological observations. Also, in making runs from one point to another, the temperature was taken at frequent intervals. These observations are reduced to the form given in the table following, to show the average temperatures at different dates or in the various localities, under the conditions described.

The thermometers used were accurate, with Kew certificates showing any error over one-tenth of a degree Fahrenheit. The deep temperatures were taken with registering thermometers of the Miller-Casella pattern, which were found very convenient. They were tested by comparison with standard thermometers throughout the range of temperature for which they were used. Any observations which appeared unreliable were checked or repeated, and results in which any uncertainty still remained, have been struck out.

Deep temperatures.—While at anchor at the various stations, the deep temperatures could only be obtained at slack water; but this answered well for the purpose in view, in obtaining any difference between one direction and the other. The deeper temperatures, at 30 and 40 fathoms, show little change with the progress of the season; and they correspond with the temperature at the same depth in Cabot strait and throughout the Gulf of St. Lawrence. The deep water in Belle Isle strait is thus very little if at all colder than elsewhere in these regions.

Results.—It must be considered unfortunate that the water temperatures give such meagre results for the purpose in view, when so much trouble was taken in obtaining them. The work done may be considered as final however; as it serves to show that in this strait the water temperature does not afford any indications regarding the movement of the water, which are sufficiently well-marked to be reliable.

The influence of these temperatures on the movements of fish may be of importance, however. The coldness of the water, especially at the greater depths, in relation to other regions in the Gulf of St. Lawrence and around the coasts of Newfoundland as ascertained by this Survey, may throw light on such questions. The temperatures may also help to explain the depths at which the fish are found as the season advances, and the change in their migrations from one season to another. The investigations of this Survey may thus afford information of practical value in such directions as these, apart from their direct bearing upon the behaviour of the currents.

Icebergs in relation to water temperature.—On August 7, 1894, an unusually large iceberg was aground in 57 fathoms off Chateau bay. An instrumental survey made in a boat, showed it to be 780 feet long, 290 feet wide and 105 feet high. The water temperatures on different sides were 38°, 37° and 37°, at distances ranging from 130 to 1,320 feet from it. On that day the water temperature, on a line from Chateau bay to Belle Isle, was 36½° off the mouth of the bay, 39° in the middle and 41° off the south end of Belle Isle. It was lowered less than 2°, therefore, in the proximity of the iceberg.

The next day, August 8, a small iceberg was aground in Chateau bay. The water temperature in the middle of the bay was 34° and at the mouth, 34½°. The lowest temperature close to the iceberg was 33½°, which shows a difference of not more than 1°, due to the iceberg.

In 1906, an iceberg about 140 feet long was aground in 38 fathoms about 1½ miles from Station P, where it remained for several days. On June 19 it was examined in a boat. The surface temperature in the strait at the time was 35½°, and close around the berg it was found to be the same, except on the west side, where the water tailing from it with the flood was 35°. There was thus only ½° difference of temperature to be found near it.

It is evident that such small differences of temperature, found closer to icebergs than a steamer would willingly venture, cannot be relied upon as an indication of value. At times when the surface temperature is higher, more difference might be expected; but this usually occurs while the dominant flow is eastward, which prevents the bergs from coming in. There is thus also little opportunity to obtain observations, as the bergs are few.

It might be thought probable that when many icebergs come into the strait, the colder water of the Labrador current off its mouth would come in with them, and thus give a general indication of their presence. Broadly speaking, this is true; but when a gale can occasion the greatest change in the surface temperature which ever occurs, as has been pointed out, it is evident that this indication cannot be relied upon.

TEMPERATURE OF THE WATER.—BELLE ISLE STRAIT.—1906.

Average temperature of the surface water in the open strait, for periods of about a week; and average of a series of observations on the various courses run in the region.

Date.		Average Temperature.	Remarks.
	1906.		
June	6...	39.[illegible]	On west coast of Newfoundland. From Rich Point to Férolle Point.
"	6...	36.4	From Férolle Point to Amour Point. (From 39° to 34°)
"	8–17...	35.6	Dominant flow both eastward and westward.
"	18–23...	35.3	" " westward throughout the week.
"	25–29...	37.9	" " " "
July	3...	44.5	From Rich Point to Férolle Point. Rise of 5° since June 6.
"	4–14...	45.9	Dominant flow eastward during this period.
"	16–18...	47.7	" " " these days.
"	19...	42.6	At mouth of strait on northern side; from Chateau bay to Station I.
"	19–21...	43.0	At eastern end of the strait, north of Belle Isle. Station L.
"	25...	44.1	Across eastern end of the strait, from Chateau bay to Station K.
"	25–28...	44.7	At eastern end of the strait, south of Belle Isle. Station K.
July Aug.	30 to 4...	50.6	Dominant flow eastward since beginning of previous week.
"	6–9...	56.2	At western end of the strait. Station S.
"	16...	52.7	Average from Red bay to middle of strait at Station P.
"	16...	57.0	At the middle of the strait. Station P.
"	17...	....	Heavy gale; north and northeast.
"	18...	45.2	Average from Red bay to middle of strait at Station P.
"	18...	44.0	At the middle of the strait. Station P.
"	20...	44.3	Average from Red bay to middle of strait at Station T.
"	20–25...	44.9	Dominant flow westward throughout this week.
"	27...	45.5	From Red bay across strait to Station U near south shore.
Aug. Sept.	27 to 1...	46.1	Tidal streams only, without dominant flow. Temperature recovering.
"	3–4...	....	Heavy gale: east to northeast.
"	5...	45.5	From Red bay across strait to Station U near south shore.
"	5...	46.0	Near south shore, at Station U.
"	7–8...	....	Very heavy northerly gale.
"	8...	45.0	From Red bay, nine miles out, to middle of strait.
"	10–13...	44.0	Strong dominant flow westward during these days.
"	17...	41.6	From Red bay to middle of strait at Station P.
"	17–22...	41.0	Strong dominant flow westward during this week.
"	25...	40.8	From Amour Point to Férolle Point. (From 39° to 42½°)
"	25...	50.5	From Férolle Point to Rich Point. (From 50° to 51°) Rise in average temperature, 11° since June 6.

DEEP TEMPERATURES.—BELLE ISLE STRAIT.—1894.

Station.	Date.		Surface.	Depth in Fathoms.				Remarks.
				10 F.	20 F.	30 F.	40 F.	
	1894.		°	°				
A	July	11	47½	45	41	36		At end of the ebb; the Eastward stream.
A	"	11	46	45	37	32½	.	On the flood; the Westward stream.
B	"	13	46	42	37	34		At slack water after the ebb.
C	"	17	47	38½	37	33	.	After ebb; dominant flow also Eastward.
C	"	18	50	41	38	36		" " "
A	"	20	50	45	43	41	..	After flood
A	"	20	50	45	41	40	.	After ebb Dominant flow Eastward, since July 16.
A	"	21	49½	47	43½	41	40	"
B	"	25	46	45	40	35	..	At slack water after short flood.
B	"	26	51	51	45	37	.	At slack water after the ebb.
B	"	27	51½	51½	39½	36½	35	" " flood.
B	"	28	52½	52	40	36½	35½	" " ebb.
G	Aug.	2	51½	37½	32	31	.	At 19 miles N. W. ½ N. from Riel Point.
—	"	3	53	52½	46½	41	39	At 12 miles N. from St. Geneviève bay.*
H	"	4	52½	51	43	37½	.	At 11½ miles N. ½ E. from Férolle Point.
—	"	6	41	41	30½	30½	30	Middle of strait, N. of Cape Norman.
—	"	7	39	38	32½	30½	30	Midway between Chateau bay and Belle Isle.
—	"	9	40	34½	32	30½	30	" " Belle Isle and Cape Bauld.
C	Sept.	8	37	..	.	..	..	Lowest observed; after long Westward flow.
B	"	12	39	38½	37	37	..	At slack water after the flood.
—	"	13	44	42½	37	35½	..	At 10½ miles N. from St. Geneviève bay.
U	"	15	40½	39	36	36	..	At slack water after the flood.
U	"	15	40	39	37	36½	..	" " ebb.
C	"	20	41	38	36	35½	..	" " "
C	"	20	42	38½	38	36	..	" " flood.
—	"	25	47	45	37½	34	33	At 17 miles N. from St. John island.

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*Towards the north shore, opposite St. Geneviève bay, the temperatures on this date were found to be nearly as low as at Station G on the line above. Compare also the temperatures here on September 13, given below.

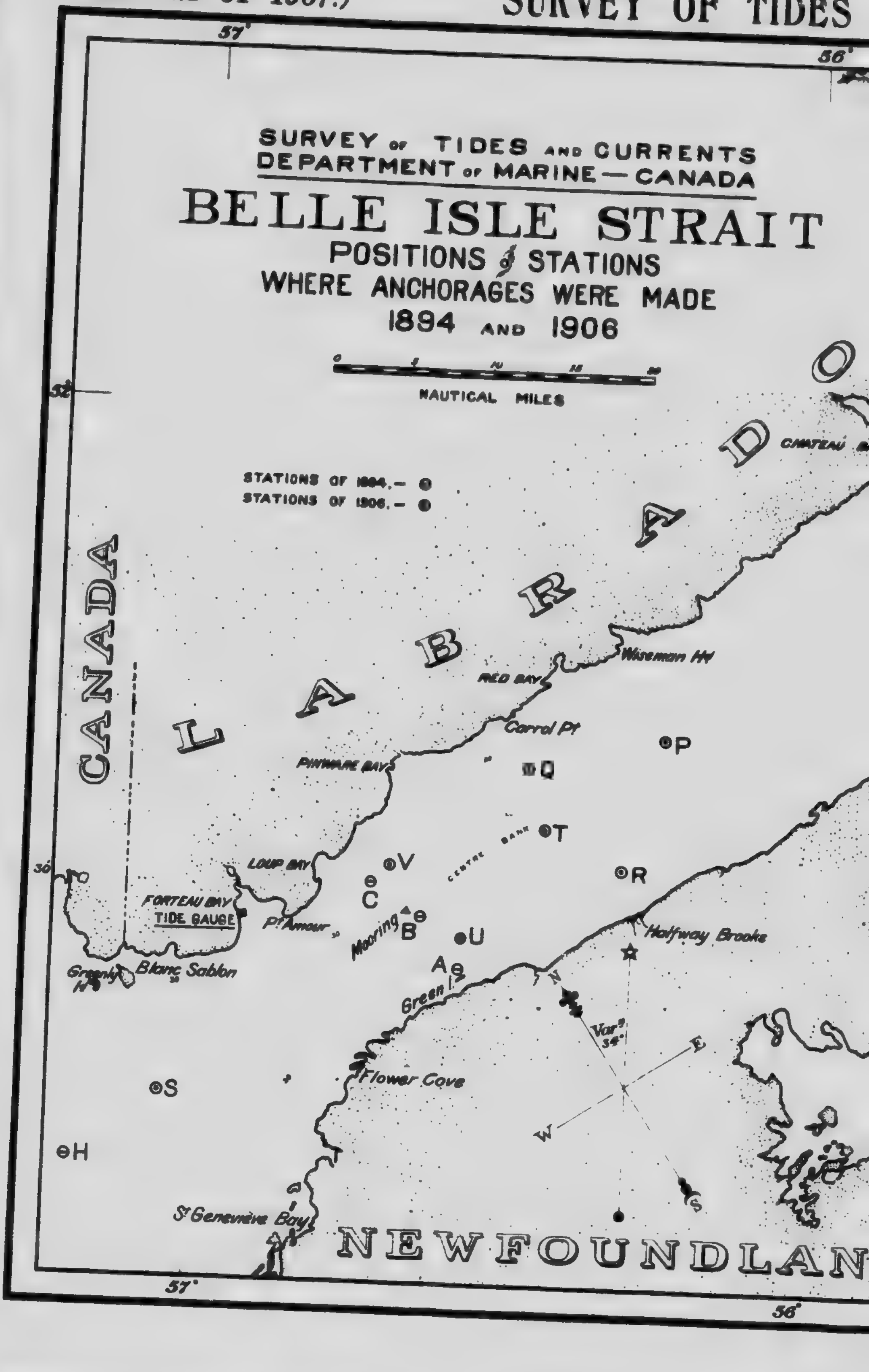
DEEP TEMPERATURES.—BELLE ISLE STRAIT —1906.

Station.	Date.		Surface.	Depth in Fathoms.					Remarks.
				5 F.	10 F.	15 F.	20 F.	30 F.	
	1906.		°	°	°	°	°	°	
N	June	14..	38	38	37	35	..	..	Near west end of strait, and after the ebb.
P	"	19..	35½	35½	..	35½	34½	..	After the flood. Dominant flow westward.
P	"	21.	35½	35½	35	..	35	..	" " " "
Q	"	28	38	38	35½	..	34½	..	At slack water after the ebb.
R	July	4.	46	42½	42½	..	42½	..	On south side; after the long run of the ebb.
R	"	10.	46	46	45½	..	44	..	" " "
R	"	13..	47½	47½	47	..	44	..	" " "
L	"	21..	42½	41½	33½	..	30½	31	Midway between Chateau bay and Belle Isle.
K	"	26..	46	43	40½	37½	33½	33	" " Belle Isle and Cape Bauld.
Q	Aug.	1.	47	46½	44½	..	38½	..	After the ebb; dominant flow eastward.
R	"	3..	54	54	53	..	42	..	After short flood, and after long ebb; dominant flow being eastward.
R	"	3.	54	54	53½	..	43½	..	
Q	"	4..	50	46	40	..	33	..	After strong westward set during the night.
P	"	16..	57	..	..	..	..	..	Highest temperature during the season.
P	"	18..	45	45	41½	37	32½	31	After N. E. gale of the 17th.
U	"	28..	45½	44	43	42	33	32	At slack water after the ebb.
Q	"	31..	46	45	43	..	..	..	" "
V	Sept.	1.	46½	45½	44	39	36	35½	After the short run of the flood.
—	"	8..	45	45	44	..	39½	..	After gale. At 1½ miles off Red bay.
V	"	11.	44	44	43	42	..	..	After continuous westward flow for 27 hours.
P	"	17..	41½	40½	40	..	39	..	After the flood. Dominant flow westward.
P	"	18.	41	..	..	..	40½	38½	After the long run of the flood.

COPY

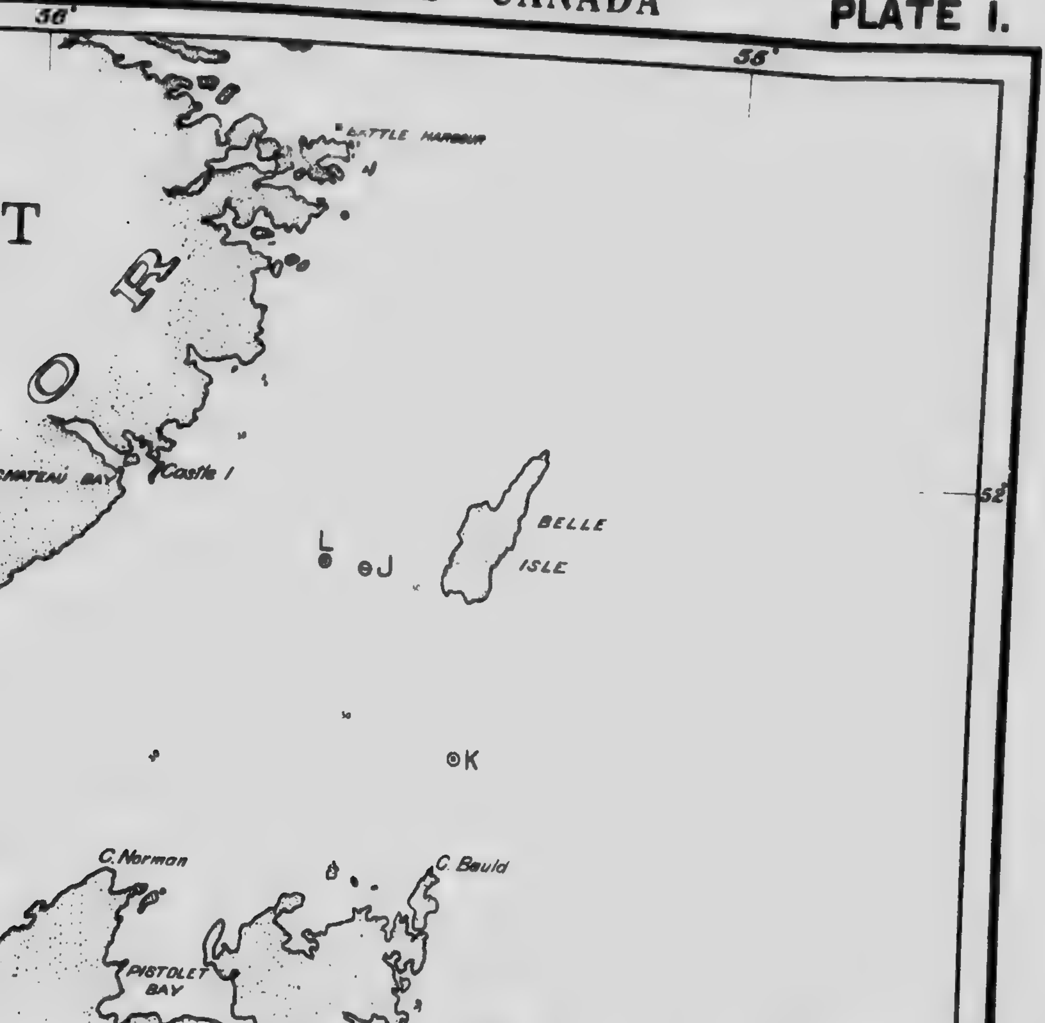
(REPORT **PLATE I.**

(REPORT OF 1907.) SURVEY OF TIDES



DES AND CURRENTS—CANADA

PLATE I.



(REPORT OF 1907.)

SURVEY OF TIDES AN

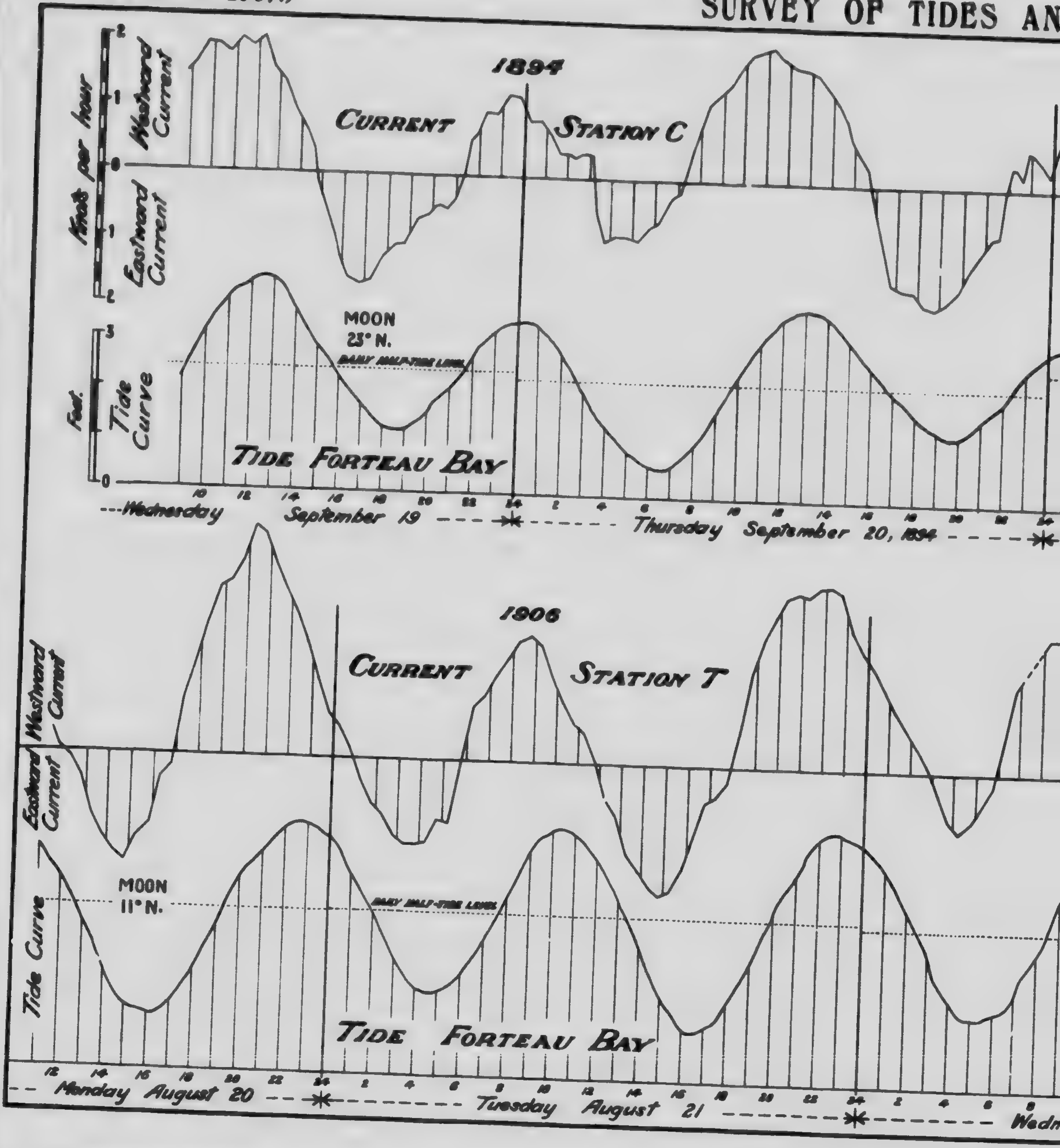
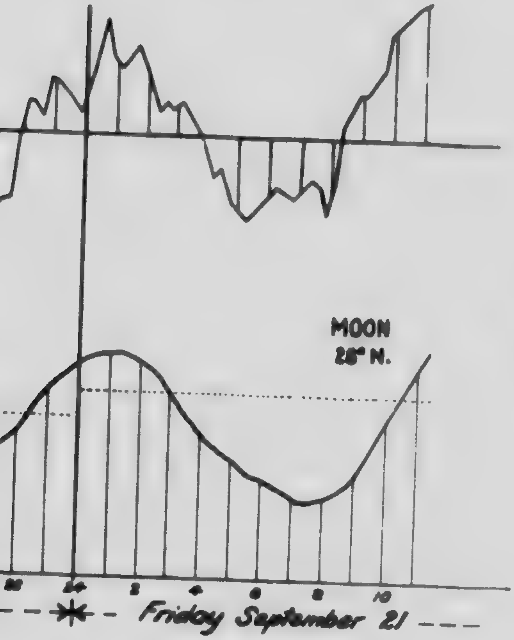


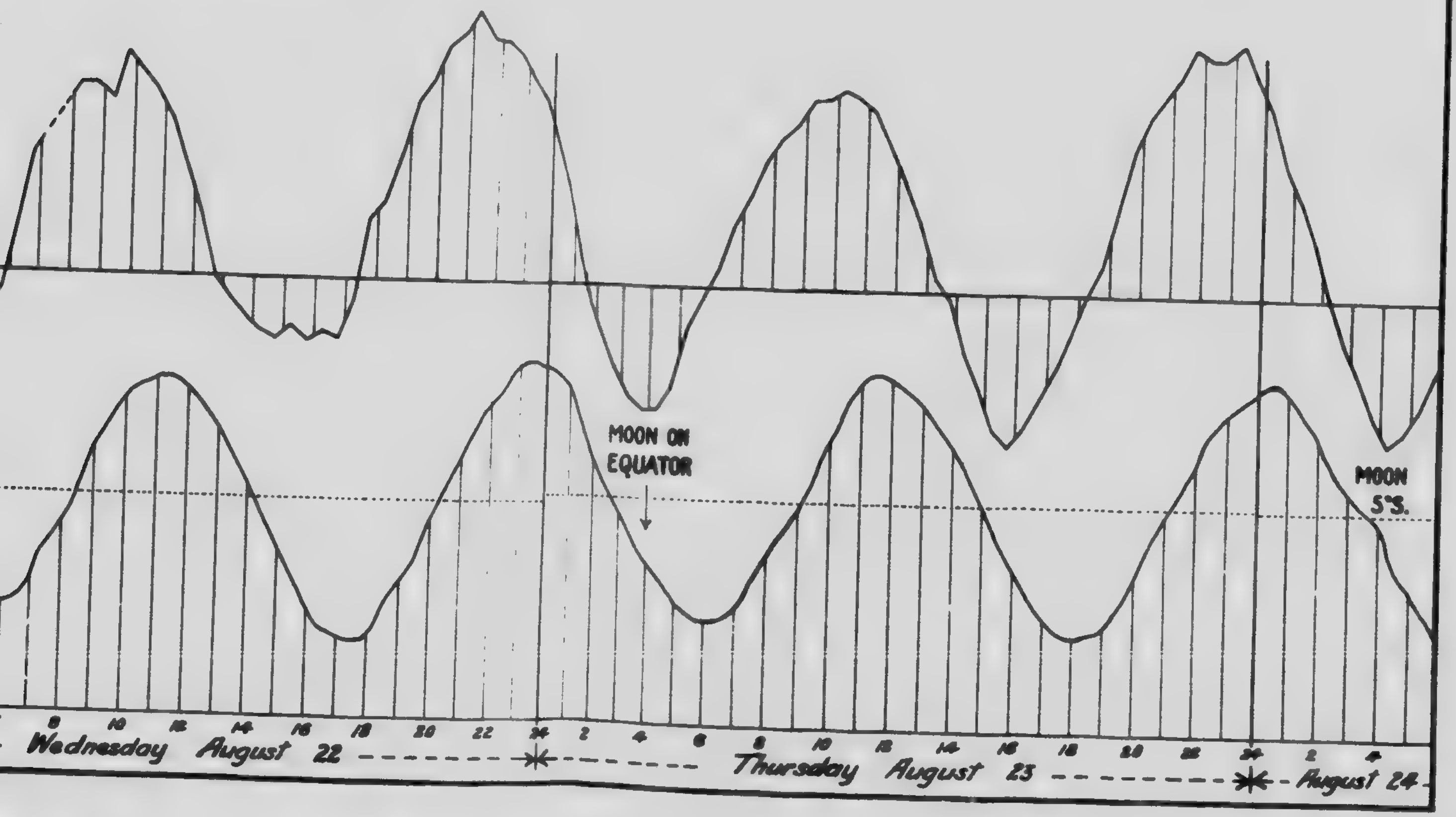
PLATE II.



TIDE AND CURRENT IN BELLE ISLE STRAIT.

PERIODS OF TIDAL EQUALITY 1894 AND 1906.

TIME:—STANDARD TIME FOR THE 60TH MERIDIAN WEST, IS USED THROUGHOUT.



SURVEY OF TIDES AND

TIDE AND CURRENT IN BELLE

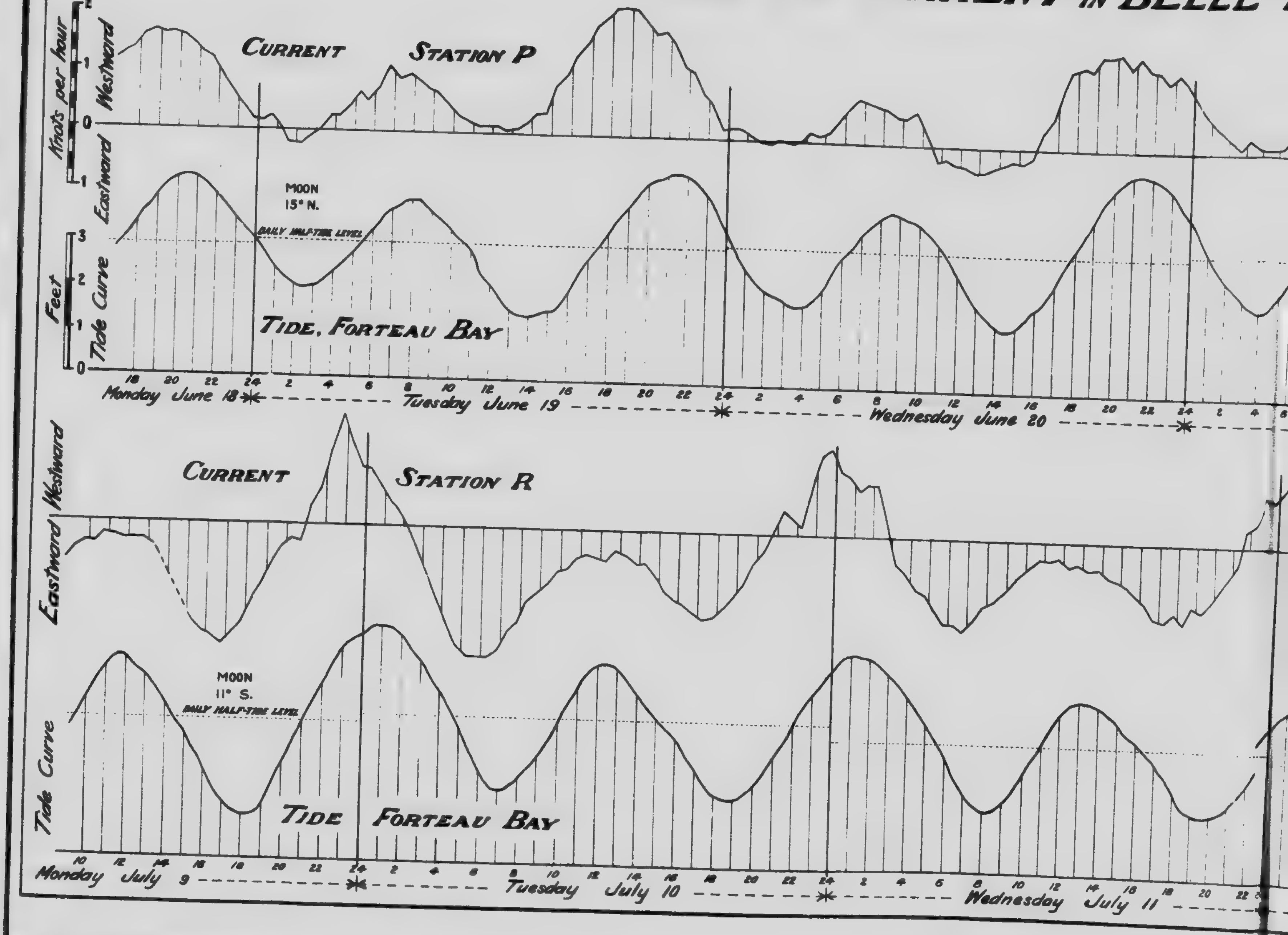
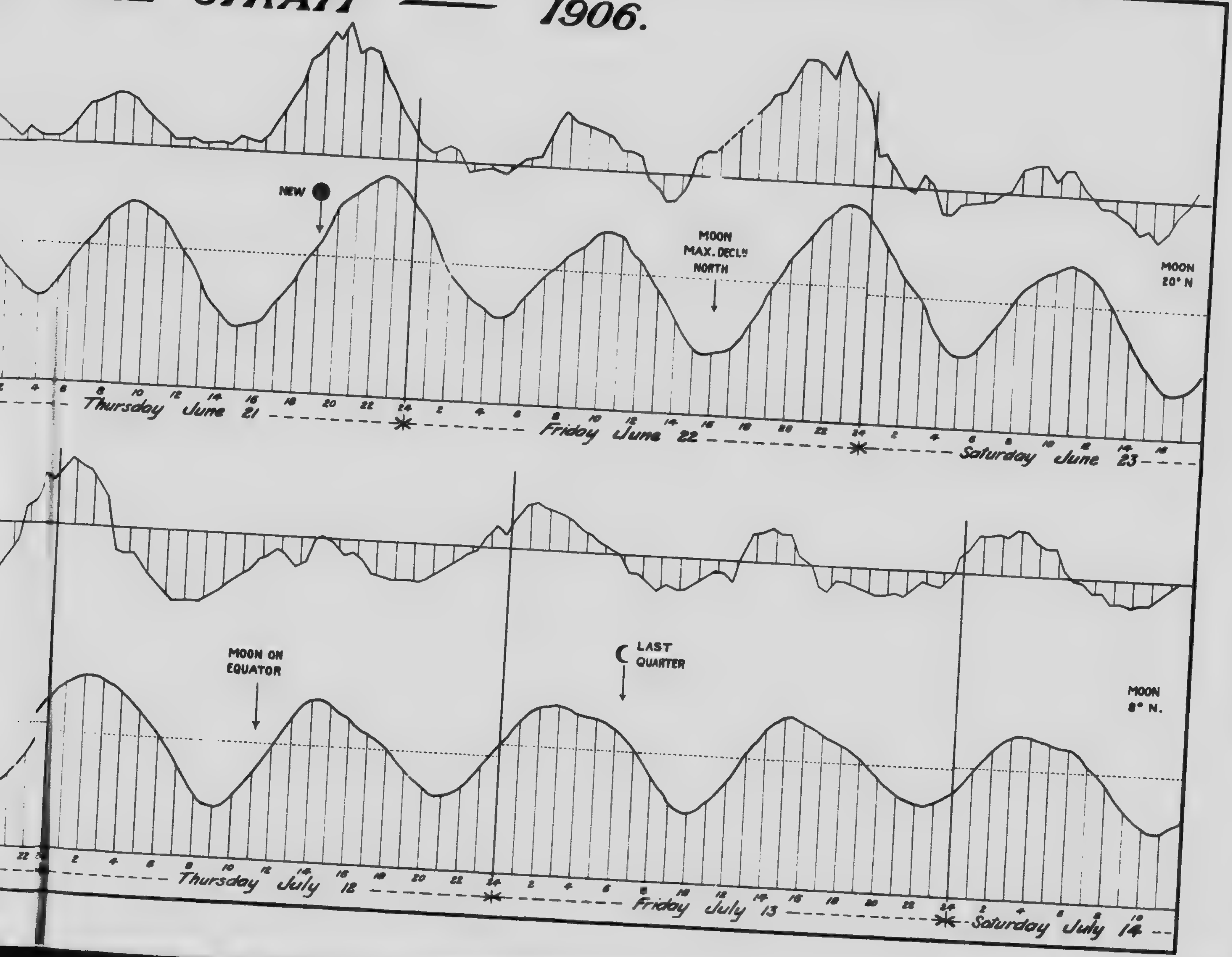
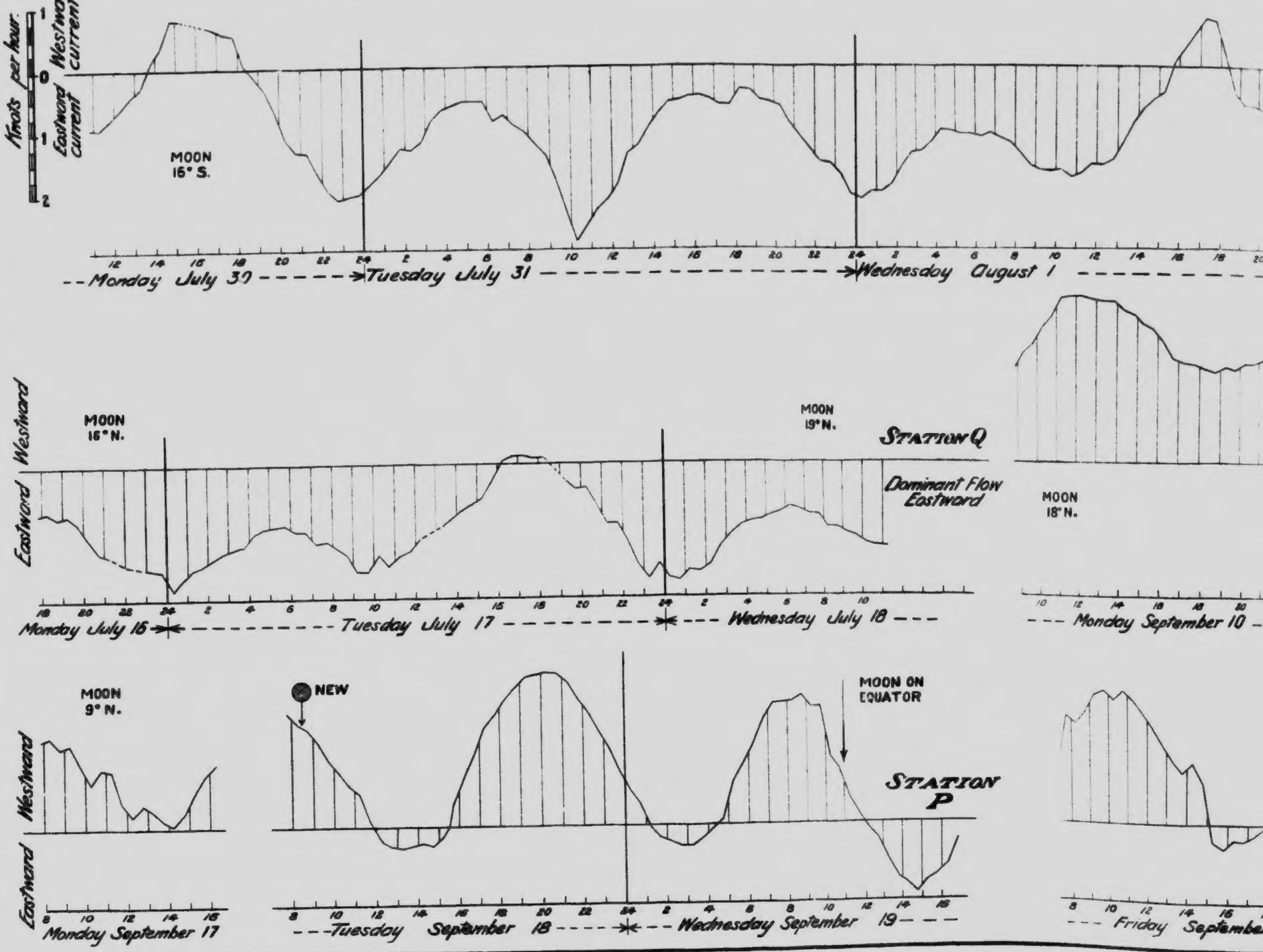


PLATE III.

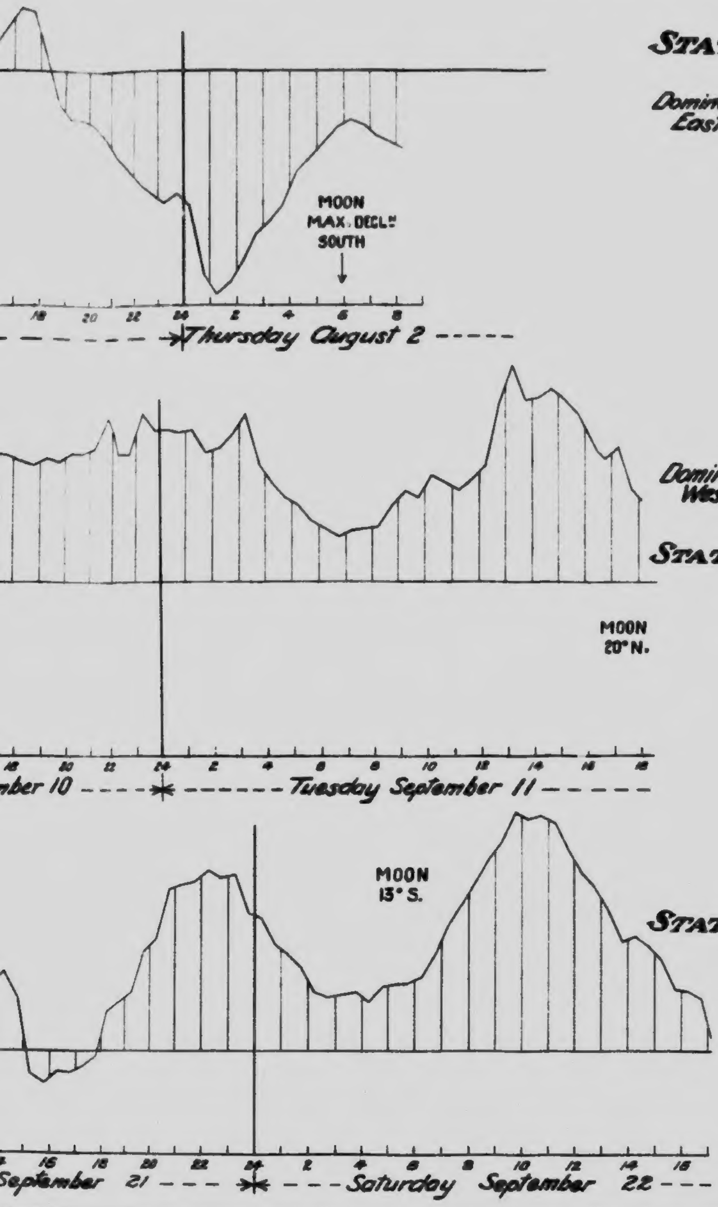
LE ISLE STRAIT —— 1906.



CURRENT IN BELLE ISLE STRAIT SHOWING DOMINAN



NANT FLOW — 1906.



DOMINANT FLOW – 1906.

REDUCED AS A SEPARATE ELEMENT

CORRESPONDING BAROMETRIC GRADIENT